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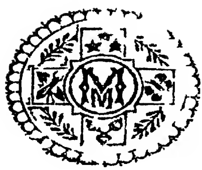

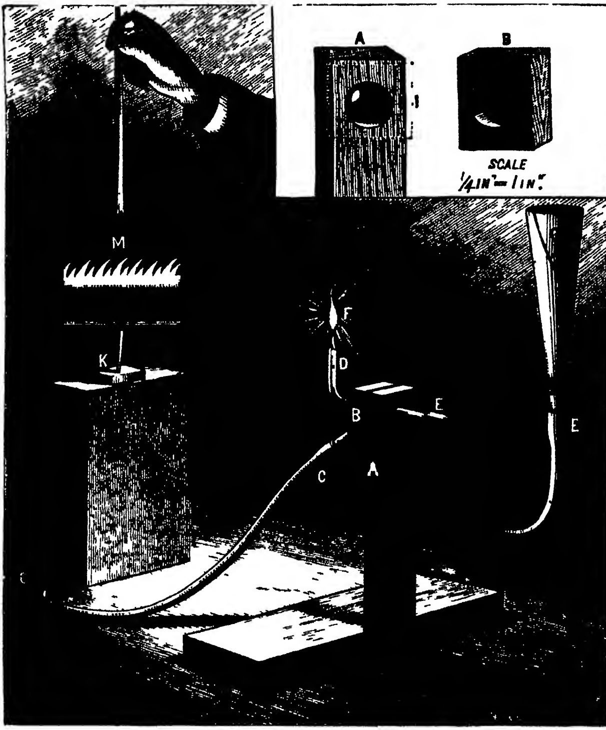

KÖNIG'S VIBRATING FLAME.

NATURE SERIES.

SOUND:

A SERIES OF

SIMPLE, ENTERTAINING, AND INEXPENSIVE EXPERIMENTS IN THE PHENOMENA OF SOUND, FOR THE USE OF STUDENTS OF EVERY AGE.

BY

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PREFACE

THE books of this Experimental Science Series originated in the earnest and honest desire to extend a knowledge of the art of experimenting, and to create a love of that noble art, which has worked so much good in our generation.

These books, though written for all those who love experiments, and wish to know how to make them with cheap and simple apparatus, will, it is hoped, be found useful to teachers, especially to the teachers and students in our Normal Schools. The majority of those who go from these schools will be called to positions where only a small amount of money can be obtained for the purchase of the apparatus needed in teaching science. These little books will show how many really excellent experiments may be made with the outlay of a few pounds, a little mechanical skill, and—*patience*. This last commodity neither I nor the school can furnish. The teacher is called on to supply this, and to give it as his share in the work of bringing the teaching of experimental science into our schools.

When the teacher has once obtained the mastery over the experiments he will never after be willing to teach without them; for, as an honest teacher, he will know that he cannot teach without them.

Well-made experiments, the teacher's clear and simple language describing them, and a free use of the black-board, on which are written the facts and laws which the experiments show—these make the best text-books for beginners in experimental science.

Teach the pupil to read Nature in the language of experiment. Instruct him to guide with thoughtfulness the work of his hand, and with attention to receive the teachings of his eyes and ears. Books are well—they are indispensable in the study of principles, generalizations, and mathematical deductions made from laws established by experiment—but, "Ce n'est pas assez de savoir les principes, il faut savoir MANIPULER."

Youths soon become enamoured of work in which their own hands cause the various actions of Nature to appear before them, and they find a new delight in a kind of study in which they receive instruction through the doings of their hands instead of through the reading of books.

The object of this second book of the series is to show how to make a connected series of experiments in Sound. These experiments are to be made with the cheapest and simplest apparatus that the author has been able to devise. I have tried to be plain in giving directions for the construction and use of this

apparatus. In my descriptions of the experiments I have endeavoured to be clear; but in this I may have failed. If I have, I am sure that the experiments themselves are true, honest, and of good report, and will supply all the shortcomings of language, which, even from the best pens, gives but a weak and incomplete conception of an experiment.

In Chapter II. is given an account of the order of the experiments. These have been carefully selected, and arranged so that one leads to the next. Each experiment has been made by me over and over again, and the series has been performed before me by beginners in the art. I therefore know that they will all succeed if my directions are perseveringly followed. The experiments are numbered in order up to 130, so that they may be referred to from this work, and from the other books of the series.

Several of the instruments described are new, and many of the experiments are so pleasing in their action that they may be of interest to my scientific brethren, and to those engaged with college classes. I would refer to the instruments or experiments described in Experiments 1, 2, 17, 33, 34, 43 to 59, 61, 65, 66, 67, 68, 69, 70, 73, 74, 78, 79, 100, 104, 105, 107, 108, 110, 112, 121, 122, 125, 126, 127.

A lively interest has recently been excited in the subject of Sound by two of the most remarkable inventions of this century: Bell's Telephone, and the Speaking and Singing Phonograph of Mr. Thomas A. Edison. The first named of these inventions will

be described in the fourth book of the series; the second I describe, with two excellent engravings, at the end of this volume.

The Experiments have been completed for the remaining books of the series, which will appear in the following order (I. "Light;" II. "Sound," already published): III. "Vision, and the Nature of Light;" IV. "Electricity and Magnetism;" V. "Heat;" VI. "Mechanics;" VII. "Chemistry;" VIII. "The Art of Experimenting with Cheap and Simple Instruments."

Mr. Barnard, who was associated with me in writing the book on "Light," found that his engagements did not permit him to continue his work on the series.

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CHAPTER I.

INTRODUCTION.

To know how the various sounds of Nature and of music are made; to understand the action of the mechanical contrivances in our throat and ears, with which we speak and hear; to be able to explain the cause of the different tones of musical instruments; to know why certain notes sounded together give harmony, while others make discord: such knowledge is certainly valuable, curious, and interesting. You may read about these things, but a better way is *to study the things themselves*, by making experiments, and these experiments will tell you better than books about the causes and the nature of sounds.

To make an experiment means to put certain things in relation with certain other things, for the purpose of finding out how they act on each other. An experiment is, therefore, a finding out.

It is the aim of this book to show you how to construct your own apparatus out of cheap and common things, and to aid you in becoming an experimenter. The student should, with patience and thoughtfulness, make each experiment in order, for they have been arranged so that one leads naturally to the making

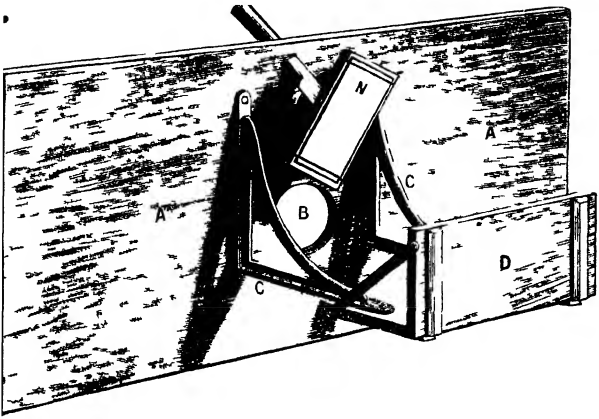
and understanding of the next. If the first, second, or even third trial does not give success, do not be discouraged, for the oldest and most gifted experimenters often fail; yet they have made noble discoveries in science by their experiments, because they had patience and perseverance, as well as skill and knowledge. Do not be disheartened, and you will become a skilful experimenter.

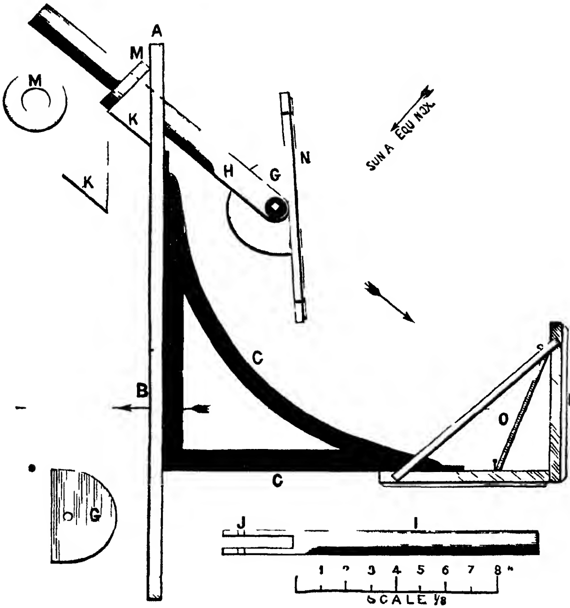
In making an experiment, we may work alone, or we may perform the work in the company of our friends, so that a large number may see what we do, and assist in making the experiment. To exhibit an experiment on a large scale, so that all the people in a room may see it, we need a magic-lantern. A lantern with a good artificial light will cost a great deal of money, but by using the water-lantern and heliostat, described in the first book of this series, and employing the sun for a light, we can exhibit many of our experiments in sound, in the most beautiful manner, before a large company, and at a trifling expense.

At the same time, the lantern is not essential, and if you do not wish to use it you can perform all of the experiments without its aid.

THE HELIOSTAT.

The word "heliostat" is formed of two Greek words—*helios*, the sun, and *statos*, standing. There is an instrument so named, because it keeps a reflected beam of sunlight constantly pointing in the same direction. In "Light" the first book of this series, we have given a description of a simple heliostat; but, as some of our readers may not have that volume, we here give a short description of the manner of making and using that instrument: The sun, in his daily apparent path through the sky, moves as though he were fixed to the surface of a vast globe, which





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makes a daily revolution around an axis. This axis is found by drawing a line from a point near the pole-star to the centre of the earth, and then continuing this line beyond the earth till it meets the heavens in a spot which can be pointed out only by those who live south of the earth's equator. This line is the axis around which the sphere of the heavens appears to

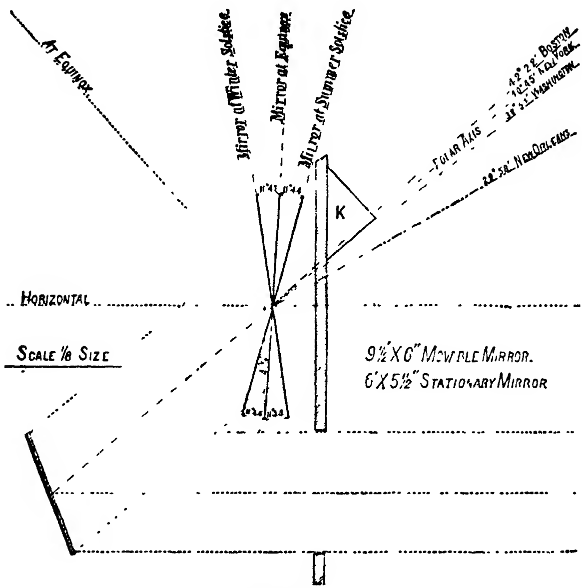


FIG. 2.

revolve once in a day. The knowledge of this motion of the sun enables us to construct an instrument with a movable mirror which will reflect his beams in one direction from sunrise to sunset.

Figs. 1 and 2 are drawings of the heliostat. The scale at the bottom of Fig. 1 gives in inches the size of the parts of the lower drawing. *H* is a round

wooden rod, which we call the polar axis of the heliostat, because it points toward the pole-star when the instrument is in the proper position for use. This axis turns freely in a hole in the board *A B*, and in the block *K*. A wooden washer *M*, which is slid over the axis and is fastened to it, rests on the block *K*, and thus keeps the axis from slipping down. The end *H* of the axis has a slot cut in it, and a semicircle of wood *G*, which is screwed to the back of a board carrying the mirror *N*, turns in this slot around a carriage-bolt, as shown in the figure. This movable mirror is fastened to the board either by strings or by elastic bands, which go round the ends of the board and mirror. The mirror should be of silvered glass, not of common looking-glass. It is, as stated in Fig. 2, 9½ inches long and 6 inches wide.

Since the sun in his daily course through the heavens appears to move as though attached to the surface of a sphere, which revolves on an axis parallel to the polar axis of the heliostat, it follows that, if we tilt the mirror *N* so that the sunbeam which strikes it is reflected downward in the direction of the polar axis *H*, then, by simply turning this axis with the sun as he moves in the sky, we can keep his rays constantly reflected in that direction. The dotted line and arrow going from the mirror *N* to *O* show the direction of the reflected rays. But this is not a convenient direction in which to have the sunbeam, so we fix at *O* another mirror, 6 inches high and 5½ inches wide, which reflects the beam from *O* to *B*, through a hole of 5 inches diameter cut in the board *A B*. Brackets, 14 × 12 inches, with their 12-inch sides screwed to the board *A B*, support a shelf *D*, which holds the mirror *O*.

Each morning in the year the sun appears on the horizon at a different point on the celestial sphere, so that on different days we have to give the mirror *N* a different tilt toward the sun. At the equinoxes, that is, on the 20th day of March and of September,

the rays fall at right angles to the axis *H*, as shown in Figs. 1 and 2, and the mirror in Fig. 1 is placed at the proper tilt for those days. In Fig. 2 the tilt of the mirror is also given for the days of the summer and winter solstices.

As we go north, say to Boston, the north star rises to a greater height above the horizon, so the axis of our heliostat at Boston must stand more upright than at New York, and have the position marked "42° 22′, Boston." Going south, say to New Orleans, we shall see the pole-star shining above the horizon at a height which is one-fourth less than the height it appears at in New York; therefore, at New Orleans, the polar axis of the heliostat is lowered into the position marked "29° 58″, New Orleans." So we see that in different latitudes the axis of our heliostat has to be placed at different angles with the horizontal line. In order that the instrument may work correctly, the angle which it should make with the horizon is the same as the latitude of the place. These are the angles written before the places named in Fig. 2. These changes in the slant of the polar axis for different latitudes need like changes in the shape of the block *K*; but if one first draws the correct line in which the axis goes through the board *A B*, the block *K* can be formed without trouble.

EXPERIMENT 1.—To place the heliostat in position for use, we raise the sash of a southern window, and secure the board *A B* between its jambs, with the mirrors outside and the polar axis inside the room. With a shawl or blanket we closely cover that part of the window above the board *A B*, so as to keep out all light except what comes into the room through the hole *B*. The movable mirror is now turned toward the sun, and tilted so that the beam from it is reflected by the fixed mirror *O* into a horizontal direction, and at right angles to the board *A B*. If the window faces the south the heliostat will work with entire success. If the window does not truly face the south, then the

board *A B* should be tilted sideways till it does face that direction, and any opening thus made between the board *A B* and the window-sash may be closed with a strip of wood.

THE WATER-LANTERN.

Fig. 3 represents a wooden box containing a mirror placed inside at an angle of 45°, and supported by wood slots fastened to the sides of the box. The side of the box opposite the mirror is open. In the top of the box is a round hole 5 inches (12·7 centimetres) in diameter. In this hole rests a hemispherical glass dish, $5\frac{1}{2}$ inches (14 centimetres) in diameter, made by cutting off the round top of a glass shade. At the back of the box is a wooden slide carrying a horizontal shelf on its top. This slide has a long slot cut in it, and, by means of a bolt and nut fastened to the back of the box, it can be made fast at any required height. This slide is 16 inches (40·6 centimetres) long, 5 inches (12·7 centimetres) wide, and $\frac{3}{4}$ inch (19 millimetres) thick. The shelf is 7 inches (17·8 centimetres) long and 5 inches (12·7 centimetres) wide, and has a hole $3\frac{1}{4}$ inches (8·3 centimetres) in diameter cut in its centre. A block of wood is fastened to the back of the box in the slot, to serve as a guide in raising and lowering the slide which carries the lens. On the hole in the shelf rests a large watch-glass, or shallow dish, about 4 inches (10·1 centimetres) in diameter. A plano-convex lens may be used in its place. On each side of the shelf are two upright wooden arms, and on screws, which go through them, is swung a looking-glass, 7 inches (17·8 centimetres) long and 4 inches (10·1 centimetres) wide.

EXPERIMENT 2.—Place this lantern before the heliostat, so that the full beam of light may be reflected from the mirror upward through the glass bowl and

the watch-glass[1] Fill each of these with clear water,

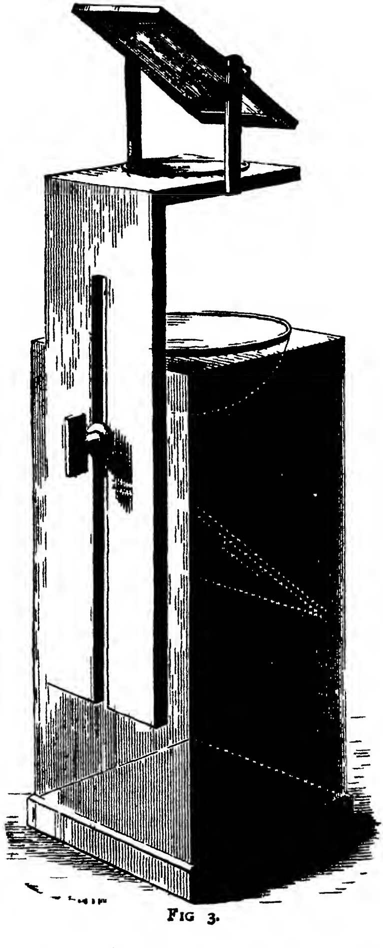


FIG 3.

[1] Dr R M. Ferguson first used a condensing lens made of a glass shade filled with water. See *Quarterly Journal of Science*, April, 1872. Subsequently, Professor Henry Morton made a watch glass filled with water, or other liquid, serve for the projecting lens of the lantern.

and then place the swinging mirror at an angle of 45°. Hang up a large screen of white cotton cloth, or sheet, in front of the lantern, and from 15 to 40 feet (4·5 to 12·2 metres) distant. On this screen will appear a circle of light projected from the lantern. Get a piece of smoked glass, and trace upon it some letters, and then lay it on the water-lens. The image of the letters will appear on the screen, in white on a black ground. If they are not distinct, loosen the nut at the back of the box, and move the wooden slide up or down till the right focus is obtained.

This water-lantern may now be used for all the work performed with ordinary magic-lanterns. Place a sheet of clear glass over the large lens, to keep the dust out of the water, and then you can lay common lantern-slides on this as in a magic-lantern.

CHAPTER II.

ON THE ORDER OF THE EXPERIMENTS IN THIS BOOK.

IN Chapter I. are explained the construction and use of the heliostat and water-lantern. In Chapter IV. we begin by experimenting on the three ways in which a body may vibrate. We show that it may swing to and fro like a pendulum; that it may vibrate by shortening and lengthening; and that it may vibrate by twisting and untwisting itself. Then we study the nature of vibratory motions, and find that they are like the motion of a swinging pendulum; and the motion of the pendulum we discover is exactly like the apparent motion of a ball looked at in the direction of the plane of a circle, in which it revolves with a uniform velocity.

We then, in Chapter V., experiment on those vibrations whose frequency is so great that they cause sound; and show, in this and the next chapter, that whenever we perceive a sound some solid, liquid, or gaseous body is in a state of rapid vibration, and that these vibrations go from the vibrating body to the ear through a solid, liquid, or gas—air being generally the medium which transmits the vibrations. These vibrations, acting on the ear, make the auditory-nerve fibrils tremble, and thus is caused the sensation of sound.

In Chapter VIII. are experiments which show *how* these vibrations are transmitted through solids, liquids, and gases, to a distance from the source of the sound. The knowledge of how the sonorous vibrations travel through the air leads to experiments in which we

make two sonorous vibrations meet, and, by their mutual action, or interference, cause rest in the air and silence to the ear. This silence may be continuous, or it may be of short duration alternating with sound, and in this case we have "beats."

Chapter IX. gives Professor Rood's very striking experiment showing the reflection of sound. In Experiment No. 73, of Chapter VIII., we show how we may readily obtain reflection of sound from a gas-flame.

In Chapter X. we give experiments with a siren made of card-board, and with it show that the pitch of sounds rises with the frequency of the vibrations causing them. With the same siren, in connection with a resonant tube tuned to a tuning-fork, we determine the number of vibrations the fork makes in a second. With the same tube and fork we then measure the velocity of sound in air. With the same siren, in Chapter XI., the experimenter finds that the notes of the gamut are given by a series of vibrations whose numbers per second bear to one another certain fixed numerical relations.

In Chapter XII. we experiment with a cheap sonometer, and find the law which connects the length of a string with the frequency of its vibrations; then, with this law in our possession, we make the sonometer give all the notes of the gamut and the sounds of the harmonic series.

In Chapters XIII., XIV., and XV., are described experiments showing the cause of the varying intensities of sounds, experiments on the sympathetic vibrations of bodies, and on the change made in the pitch of a sounding body by moving it.

The cause of the different quality of sounds is explained in Chapter XVI., and then follow, in Chapter XVII., experiments on the analysis of compound sounds, and on the formation of compound sounds by sounding together the simple sounds which compose them. In this chapter is also found an

experiment in which is reproduced the motion of a molecule of air when it is acted on, at the same time, by the vibrations giving the first six harmonics of a compound sound; also, directions for making a very simple form of Konig's vibrating flame, and a cheap revolving mirror in which to view the flame.

Chapter XVIII. contains experiments on the voice in talking and singing. After explaining how we speak, we give experiments on the resonance of the oral cavity, and then show how a toy trumpet can be made to speak, and a talking machine made out of the trumpet and an orange. This chapter concludes with accounts of the talking machine of Faber of Vienna, and of the recently invented talking and singing machine of Mr. Edison, which is indeed the acoustic marvel of the century.

Chapter XIX. concludes the book, and gives a short explanation of the causes of harmony and discord.

CHAPTER III.

ON THE NATURE OF SOUND.

SOUND is the sensation peculiar to the ear. This sensation is caused by rapidly succeeding to-and-fro motions of the air which touches the outside surface of the drum-skin of the ear. These to-and-fro motions may be given to the air by a distant body, like a string of a violin. The string moves to and fro, that is, it *vibrates.* These vibrations of the string act on the bridge of the violin, which rests on the belly or sounding-board of the instrument. The surface of the sounding-board is thus set trembling, and these tremors, or vibrations, spread through the air in all directions around the instrument, somewhat in the manner that water-waves spread round the place where a stone has been dropped into a quiet pond. These tremors of the air, however, are not sound, but the cause of sound. Sound, as we have said, is a *sensation;* but, as the cause of this sensation is always vibration, we call those vibrations which give this sensation *sonorous vibrations.* Thus, if we examine attentively the vibrating string of the violin, we shall see that it looks like a shadowy spindle, showing that the string swings quickly to and fro; but, on closing the ears, the sensation of sound disappears, and there remains to us only the sight of the quick to-and-fro motion which, the moment before, caused the sound.

Behind the drum-skin of the ear is a jointed chain of three little bones. The one, *H* of Fig. 4, attached to the drum-skin, is called the *hammer;* the next, *A*, is called the *anvil;* the third, *S*, has the exact form of a stirrup, and is called the *stirrup-bone.* This last

bone of the chain is attached to an oval membrane, which is a little larger than the foot of the stirrup. This oval membrane closes a hole opening into the cavity forming the *inner ear;* a cavity tunneled out of the hardest bone of the head, and having a very complex form. The oval hole just spoken of opens into a globular portion of the cavity, known as the vestibule, and from this lead three semicircular canals,

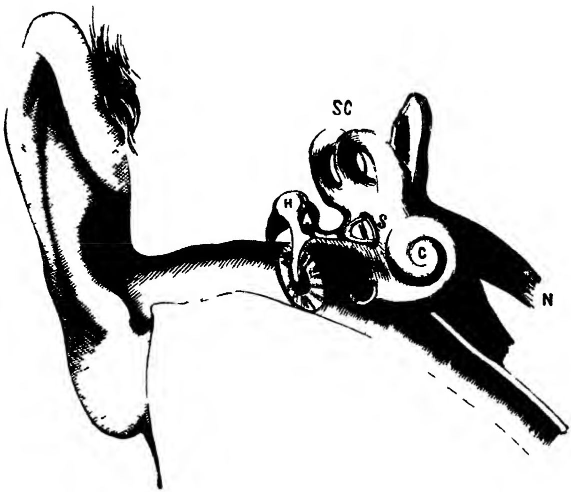


FIG. 4.

SC, and also a cavity, *C*, of such a marked resemblance to a snail's shell that it is called *cochlea*, the Latin word for that object. The cavity of the inner ear is filled with a liquid, in which spread out the delicate fibres of the auditory nerve.

Let us consider how this wonderful little instrument acts when sonorous vibrations reach it. Imagine the violin-string vibrating 500 times in one second. The sounding-board also makes 500 vibrations in a second.

The air touching the violin is set trembling with 500 tremors a second, and these tremors speed with a velocity of 1,100 feet in a second in all directions through the surrounding air. They soon reach the drum-skin of the ear. The latter, being elastic, moves in and out with the air which touches it. Then this membrane, in its turn, pushes and pulls the little ear-bones 500 times in a second. The last bone, the little stirrup, finally receives the vibrations sent from the violin-string, and sends them into the fluid of the inner ear, where they shake the fibres of the auditory nerve 500 times in a second. These tremors of the nerve—how we know not—so affect the brain that we have the sensation which we call sound. The description we have just given is not that of a picture created by the imagination, but is an account of what really exists, and of what can actually be seen by the aid of the proper instruments.

A body may vibrate more or less frequently in a second; it may swing over a greater or less space; and it may have several minute tremors while it makes its main swing. These differences in vibrations make sounds higher or lower in pitch, loud or soft, simple or compound. It is easy to say all this, but really, to understand it, one must make experiments and discover these facts for himself.

CHAPTER IV.

ON THE NATURE OF VIBRATORY MOTIONS.

THE character of a sound depends on the nature of the vibrations which cause it, therefore our first experiments will be with vibrations which are so slow that we can study the nature of these peculiar motions. These experiments will be followed by others on vibrations of the same kind, only differing in this—that they are so rapid and frequent that they cause sounds. A correct knowledge of the nature of these motions lies at the foundation of a clear understanding of the nature of sound. We hope that the student will make these experiments with care, and keenly observe them.

EXPERIMENT 3.—At the toy-shops you can buy for a few pence a wooden ball having a piece of elastic rubber fastened to it. Take out the elastic and lay it aside, as we shall need it in another experiment. Get a piece of fine brass wire, about 2 feet (61 centimetres) long, and fasten it to the ball. The weight of the ball should pull the wire straight, and, if it does not, a finer wire must be used. Hold the end of the wire in the left hand, and with the right hand draw the ball to one side. Let it go, and it will swing backward and forward like the pendulum of a clock. This kind of movement we call a *pendulous* or *transverse vibration.*

EXPERIMENT 4.—Cut out a narrow triangle of paper, 4 inches (10 centimetres) long, and paste it to the bottom of the ball. Twist the wire which supports the ball by turning the latter half round, and watch the paper pointer as it swings first one way and then

the other. Here we have another kind of vibration, a motion caused by the twisting and untwisting of the wire. Such a motion is called a *torsional vibration.*

EXPERIMENT 5.—Take off the wire and the paper and put the elastic on the ball. Hold the end of the elastic in one hand, and with the other pull the ball gently downward, then let it go. It vibrates up and down in the direction of the length of the elastic. Hence we call this kind of motion a *longitudinal vibration.*

These experiments show us the three kinds of vibrations: transverse, torsional, and longitudinal. They differ in direction, but all have the same manner of moving; for the different kinds of vibration, transverse, longitudinal, and torsional, go through motions with the same changes in velocity as take place in the swings of an ordinary pendulum. These vibrations all start from a position of momentary rest. The motion begins slowly, and gets faster and faster till the body gains the position it naturally has when it is at rest—at this point it has its greatest velocity. Passing this point, it goes slower and slower till it again comes momentarily to rest, and then begins its backward motion, and repeats the same changes in velocity.

It is now necessary that the student should gain clear ideas of the nature of this pendulous motion. It is the cause of sound. It exists throughout all the air in which a sound may be perceived, and, by the changes in the number, extent of swing, and combinations of these pendular motions, all the changes of pitch, of intensity, and of quality of sound are produced. Therefore, the knowledge which we now desire to give the reader lies at the very foundation of a correct understanding of the subject of this book.

An experiment is the key to this knowledge. It is the experiment with

THE CONICAL PENDULUM.

An ordinary pendulum changes its speed during its swings right and left exactly as a ball *appears* to change its speed when it revolves with a uniform speed in a circle, and we look at it along a line of sight which is in the plane of the circle.

EXPERIMENT 6.—Let one take the ball and wire to the farther end of the room, and by a slight circular motion of the end of the wire he must cause the ball to revolve in a circle. Soon the ball gets into a uniform speed round the circle, and then it forms what is called a conical pendulum; a kind of pendulum sometimes used in clocks. Now stoop down till your eye is on a level with the ball. This you will know by the ball appearing to move from side to side *in a straight line.* Study this motion carefully. It reproduces exactly the motion of an ordinary pendulum of the same length as that of the conical pendulum. From this it follows that the greatest speed reached during the swing of an ordinary pendulum just equals the uniform speed of the conical pendulum. That the apparent motion you are observing is really that of an ordinary pendulum, you will soon prove for yourself to your entire satisfaction; and here let me say that one principle or fundamental fact seen in an experiment and patiently reflected on is worth a chapter of verbal descriptions of the same experiment.

Suppose that the ball goes round the circle of Fig. 5 in two seconds; then, as the circumference is divided into 16 equal parts, the ball moves from 1 to 2, or from 2 to 3, or from 3 to 4, and so on, in one-eighth of a second. But to the observer, who looks at this motion in the direction of the plane of the paper, the ball *appears* to go from 1 to 2, from 2 to 3, from 3 to 4, &c., on a line *A B*, while it really goes from 1 to 2, from 2 to 3, from 3 to 4, &c., in the circle. The ball

when at 1 is passing directly across the line of sight, and therefore appears with its greatest velocity; but when it is in the circle at 5 it is going away from the observer, and when at 13 it is coming toward him, and therefore, although the ball is really moving with its regular speed when at 5 and 13, yet it appears

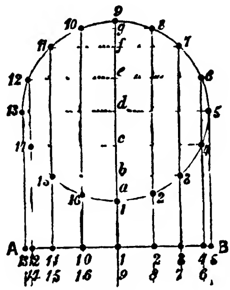


FIG. 5

when at these points momentarily at rest. From a comparison of the similarly numbered positions of the ball in the circle and on the line *A B*, it is evident that the ball appears to go from *A* to *B* and from *B* back to *A* in the time it takes to go from 13, round the whole circle, to 13 again. That is, the ball appears to vibrate from *A* to *B* in the time of one second, in which time it really has gone just half round the circle. A comparison of the unequal lengths, 13 to 12, 12 to 11, 11 to 10, &c., on the line *A B*, over which the ball goes in equal times, gives the student a clear idea of the varying velocity of a swinging pendulum.

THE SAND-PENDULUM.

Fig. 6 represents an upright frame of wood standing on a platform and supporting a weight that hangs by

a cord. *A A* is a flat board about 2 feet (61 centimetres) long and 14 inches (35·5 centimetres) wide. *B B* are two uprights so high that the distance from the under side of the cross-beam *C* to the platform *A A* is exactly $41\frac{1}{10}$ inches (1 metre and 45 millimetres). The cross-beam *C* is 18 inches (45·7 centimetres) long. At *D* is a wooden post standing

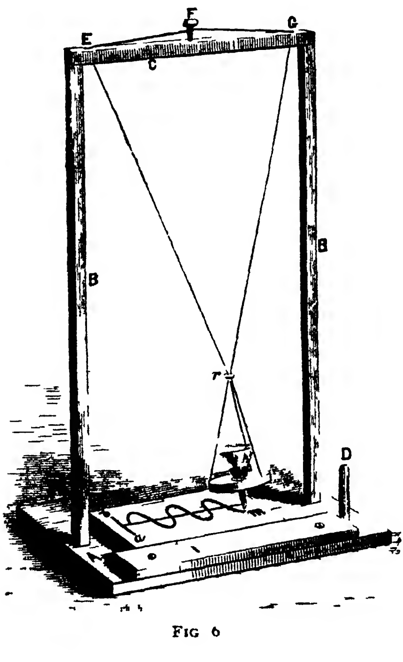


Fig 6

upright on the platform. Get a lead disk, or bob, $3\frac{3}{16}$ inches (8 centimetres) in diameter and $\frac{5}{8}$ inch (16 millimetres) thick. In the centre of this is a hole 1 inch (25 millimetres) in diameter. This disk may easily be cast in sand from a wooden pattern. At the tinner's we may have made a little tin cone $1\frac{3}{16}$

inches (30 millimetres) wide at top and $2\frac{1}{4}$ inches (57 millimetres) deep, and drawn to a fine point. Carefully file off the point till a hole is made in the tip of the cone of about $\frac{1}{16}$ inch in diameter. Place the tin cone in the hole in the lead disk, and keep it in place by stuffing wax around it. A glass funnel, as shown in the figure, may be used instead of the tin cone. With an awl drill three small holes through the upper edge of the bob at equal distances from each other. To mount the pendulum, we need about 9 feet (271·5 centimetres) of fine strong cord, like trout-line. Take three more pieces of this cord, each 10 inches (25·4 centimetres) long, and draw one through each of the holes in the lead bob and knot it there, and then draw them together and knot them evenly together above the bob, as shown in the figure. On the cross-bar, at the top of the frame, is a wooden peg shaped like the keys used in a violin. This is inserted in a hole in the bar—at *F* in the figure. Having done this fasten one end of the piece of trout-line to the three cords of the bob, and pass the other end upward through the hole marked *E*; then pass it through the hole in the key *F*; turn the key round several times; then pass the cord through the hole at *G*, to the bob, and fasten it there to the cords. Then get a small bit of copper wire and bend it once round the two cords just above the knot, as at *r* in the figure. We do not need this wire ring, and the upright post at the side of the platform at present, but they will be used in future experiments with this pendulum.

Tack on the platform *A A* a strip of wood *I*. This serves as a guide, along which we can slide the small board *m*, on which is tacked a piece of paper.

EXPERIMENT 7.—Fill the funnel with sand, and, while the pendulum is stationary, steadily slide the board under it. The running sand will be laid along *L M*, Fig. 7, in a straight line. If the board was slid under the sand during exactly two seconds of time,

then the length of this line may stand for two seconds, and one-half of it may stand for one second, and so on. Thus, we see how time may be recorded in the length of a line.

Brush off the heaps of sand at the ends of the line, and bring the left-hand end of the sand-line directly under the point of the funnel, when the latter is at rest. Draw the lead bob to one side, to a point which is at right angles to the length of the line, and let it go. It swings to and fro, and leaves a track of sand, *a b*, which is at right angles to the line *L M*, Fig. 7.

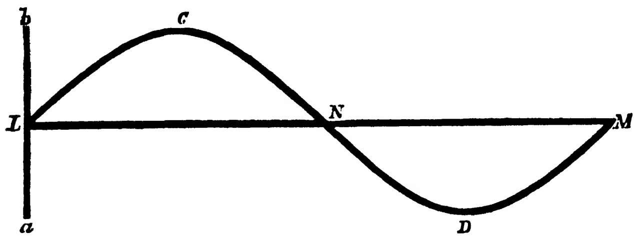


FIG. 7.

Suppose that the pendulum goes from *a* to *b*, or from *b* to *a*, in one second, and that, while the point of the funnel is just over *L*, we slide the board so that, in two seconds, the end *M* of the line *L M* comes under the point of the funnel. In this case, the sand will be strewed by the pendulum to and fro, while the paper moves under it through the distance *L M*. The result is, that the sand appears on the paper in a beautiful curve, *L C N D M*. Half of this curve is on one side of *L M*, the other half on the opposite side of this line.

The experimenter may find it difficult to begin moving the paper at the very instant that the mouth of the funnel is over *L*; but, after several trials, he will succeed in doing this. Also, he need not keep

the two sand-lines, *L M* and *a b*, on paper during these trials; he may as well use their traces, made by drawing a sharply-pointed pencil through them on to the paper.

By having a longer board, or by sliding the board slowly under the pendulum, a trace with many waves in it may be formed, as in Fig. 8.

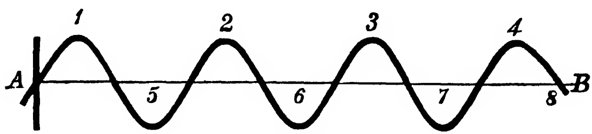


FIG. 8.

As the sand-pendulum swung just like an ordinary pendulum when it made the wavy lines of Figs. 7 and 8, it follows that these lines must be peculiar to the motion of a pendulum, and may serve to distinguish it. If so, this curve must have some sort of connection with the motion of the conical pendulum described in Experiment 6. This is so, and this connection will be found out by an attentive study of Fig. 9.

In this figure we again see a wavy curve, under the same circular figure which we used in explaining how the motion of an ordinary pendulum may be obtained from the motion of a conical pendulum. This wavy curve is made directly from measures on the circular figure, and certainly bears a striking resemblance to the wavy trace made by the sand-pendulum in Experiment 7. You will soon see that to prove that these two curves are precisely the same, is to prove that the apparent motion of the conical pendulum is exactly like the motion of the ordinary pendulum.

The wavy line of Fig. 9 is thus formed: The dots on *A B*, as already explained, show the apparent places of the ball on this line, when the ball really is at the points correspondingly numbered on the

circumference of the circle. Without proof, we stated that this apparent motion on the line *A B* was exactly like the motion of a pendulum. This we must now prove. The line *L M* is equal to the circumference of the circle stretched out It is made thus: We take in a pair of dividers the distance 1 to 2, or 2 to 3, &c., from the circle, and step this distance off 16 times on the line *L M*; hence *L M* equals the length of the circumference of the circle. *In time* this length stands for two seconds, for the ball in Experiment 6 took two seconds to go round the circle. This same length, you will also observe, was made in the same time as the sand-line *L M* was made in Experiment 7. In Fig. 9 the length *L M*, of two seconds, is divided into 16 parts; hence each of them equals one-eighth of a second, just as the same lengths in the circle equal eighths of a second. Thus the line *L M* of Fig. 9, as far as a record of time is concerned, is exactly like the sand-line *L M* of Experiment 7, and the line *A B* of Fig. 9, in which the ball appeared to move, is like the line *a b* of Fig. 7, along which the sand-pendulum swung.

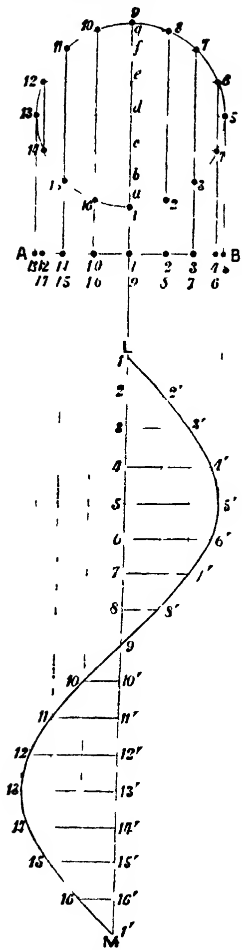


FIG. 9

Now take the lengths from 1 to 2, 1 to 3, 1 to 4. 1 to 5, and so on, from the line *A B* of Fig. 9, and place these

lengths at right angles to the line $L M$ at the points 1, 2, 3, 4, 5, and so on; by doing so we actually take the distances at which the ball appeared from 1 (its place of greatest velocity), and transfer them to $L M$; therefore these distances correspond to the distances from $L M$, Fig. 7, to which the sand-pendulum had swung at the end of the times marked on $L M$ of Fig. 9.

Join the ends of all these lines, 2 2′, 3 3′, 4 4′, &c., by drawing a curve through them, and we have the wavy line of Fig 9.

This curve evidently corresponds to the curve $L C N D M$ of Fig. 7 made by the sand-pendulum; and it must be evident that, if this curve of Fig. 9 is *exactly* like the curve traced by the sand-pendulum in Experiment 7, it follows that the *apparent* motion of the conical pendulum, as seen in the plane in which it revolves, is exactly like the *real* motion of an ordinary pendulum.

EXPERIMENT 8.—To test this, we make on a piece of paper one of the wavy curves exactly as we made the one in Fig. 9, and we tack this paper on the board $L M$ of the sand-pendulum, being careful that when the board is slid under the stationary pendulum the point of the funnel should go precisely over the centre line $L M$ (Fig. 9) of the curve.

Now draw the point of the funnel aside to a distance from the line $L M$ equal to one-half of $A B$, or, what is the same, from 5 to 5′ of Fig. 9. Pour sand in the funnel and let the bob go. At the moment the point of the funnel is over L, slide the board along so that, when the point of the funnel comes the third time to the line $L M$, it is at the end M of this line. You may not succeed in doing this at first, but after several trials you will succeed, and then you will have an answer from the pendulum as to the kind of motion it has, for you will see the sand from the swinging pendulum strewed precisely

over the curve you placed under it. Thus you have conclusively proved that the apparent motion of the conical pendulum, along the line *A B*, is exactly like the swinging motion of an ordinary pendulum.

As it is difficult to start the board with a uniform motion at the very moment the pendulum is over the line *L M*, it may be as well to tack a piece of paper on the board with no curve drawn on it, and then practise till you succeed in sliding the board under the pendulum, through the distance *L M*, in exactly the time that it takes the pendulum to make two swings. Now, if you have been careful to have had the swing of your pendulum just equal to *A B*, or from 5 to 5′ on the drawing of the curve, you will have made a curve in sand which is precisely like the curve you have drawn; for, if you trace the sand-curve on the paper by carefully drawing through it the sharp point of a pencil, and then place this trace against a window-pane with the drawing of the curve, Fig 9, directly over it, you will see that one curve lies directly over the other throughout all their lengths.

This curve, which we have made from the circle in Fig. 9, and have traced in sand by the pendulum, is called *the curve of sines*, or the *sinusoid*. It is so called because it is formed by stretching the circumference of a circle out into a line, and then dividing this line, *L M* of Fig. 9, into any number of equal parts. From the points of these divisions, 1, 2, 3, 4, 5, &c., of *L M*, we erect perpendiculars, 2 2′, 3 3′, 4 4′, 5 5′, &c., equal to the lines *a* 2, *b* 3, *c* 4, *d* 5, &c., in the circle. These lines in the circle are called *sines;* so, when we join the ends of these lines erected to the straightened circumference, by a curve, we form the curve of sines, or the sinusoid.

The sinusoid occurs often during the study of natural philosophy. It is almost sure to appear in any book on the nature of Light, and it certainly will in one on Heat.

AN EXPERIMENT WHICH GIVES US THE TRACE OF A VIBRATING PINE ROD.

A in Fig. 10 represents a rod 4 feet (121·9 centimetres) long, 1 inch (25 millimetres) wide, and $\frac{1}{4}$ inch (6 millimetres) thick. made of clear, well-seasoned pine. This is fastened by means of small screws to the wooden box *B* standing on a table. This box may be of any convenient size; but, as it is to be used for another experiment, it may be made about 14 inches (35·5 centimetres) square and 30 inches (76·2 centimetres) high. A shoe-box will

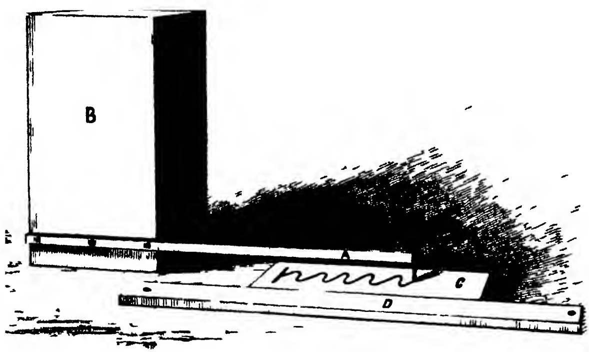


Fig. 10.

answer for the purpose. This box is placed on the table, and then filled half full of sand, and it thus gives us a firm and solid block against which to fasten the rod. The lower edge of the rod is placed about $1\frac{1}{2}$ inches (38 millimetres) above the table, with about 3 feet (91·4 centimetres) projecting beyond the box. At the free end is fastened a small camel's-hair pencil, with its tip cut off square. When these things are in place, get a narrow piece of board, *C*,

just thick enough to touch the tip of the pencil on the rod when the board is laid on the table under it. Then tack down a strip of wood, *D*, parallel with the rod, to serve as a guide for the board. On the board tack a sheet of white paper. Dip a pen in thick black ink, and wet the pencil with it. The paper-covered board is now laid under the rod, with the pencil just touching it.

EXPERIMENT 9.—Now draw the end of the rod to one side and let it vibrate. The pencil will make a trace on the paper which is nearly straight. Make it vibrate again, and then slide the paper-covered board steadily and quickly to the left, and the pencil will make on the paper a sinuous trace.

Examine this wavy line attentively. It looks very much like the curve of sines which the sand-pendulum traced for us. If it should be *exactly* like that curve, what would it show? Surely, nothing less than that the rod vibrates to and fro with the same kind of motion as a swinging pendulum. To test this supposition make the following experiment:

EXPERIMENT 10.—Obtain a trace of the vibrating pine rod in which each flexure in the trace is of the same length. This we will only get when we move the paper with a uniform velocity under the vibrating rod. Now, obtain a trace in sand, on another paper-covered board, drawn under the sand-pendulum. This trace must be made by swings of the pendulum which exactly equal the breadth of the swings made by the vibrating rod. Draw the board under the sand-pendulum with different velocities, till you succeed in making the waves of the sand just as long as those made by the vibrating rod. That is to say, the distances from 1 to 2, or from 5 to 6, of Fig. 8, must be the same in both traces. Now, with a pencil, carefully draw a line through the centre of the curve traced in sand. Remove the papers from their boards and place one over the other on a window-pane

After a few adjustments, you will see that one curve lies exactly over the other, showing that they are exactly the same in form.

Thus you have yourself found out this very important truth in science: A vibrating rod swings to and fro with the same kind of motion as a swinging pendulum.

THE PENDULAR MOTION REPRODUCED FROM THE TRACES OF THE PENDULUM AND VIBRATING ROD.

We have seen that the pendulum and vibrating rod give traces of the curve sines. We shall now show how, from this curve, we may get again the pendular motion which traced it.

EXPERIMENT 11.—Get a post-card and cut in it a narrow slit $\frac{1}{25}$ inch (1 millimetre) wide, and slightly longer than the sinusoidal trace of the vibrating rod, or pendulum. Lay this over the trace, near one end, so that you can see a small part of the trace through the slit, as is shown in Fig. 11. Move the card over

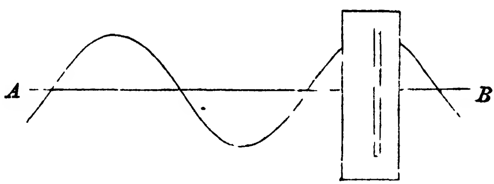


FIG. 11.

the trace, in the direction of the line *A B*, and you will see the little dot swing backward and forward in the slit, and exactly repeating the motions of the pendulum or vibrating rod.

We shall hereafter see (Chapter VII. and Experiments 58 and 110) that the molecules of air, and of other elastic bodies, swing to and fro in the line of

the direction in which sonorous vibrations are travelling through them. In the above experiment (11), this direction is represented by the direction of the length of the slit; or, as it is generally stated, the *sound* is moving in the direction of the length of the slit.

EXPERIMENT 12.—Another method of exhibiting this matter is to take off the pen and fasten, with wax, a little point of tinsel on the end of the rod, so that it just touches a piece of smoked glass laid under it. Vibrate the rod and slide the glass under it, and we shall get a sinuous trace on the glass.

To prepare the smoked glass, lay a piece of gum-camphor, about the size of a pea, on a brick. Then bend a piece of tin into the shape of a funnel, about 2 inches high, and cut a number of little notches round the bottom. Set fire to the camphor and place the funnel over it, and then by moving the glass about in the smoke which comes from the funnel it will soon be well blackened.

In exhibiting this trace in the lantern, so that several can see it at once, it is best to keep the card with the slit still and move the glass over it, and then the audience will see on the screen a white spot on a dark ground, moving with precisely the motion of a pendulum.

BLACKBURN'S DOUBLE PENDULUM.

EXPERIMENT 13.—Let us return to our sand-pendulum. We have examined the vibrations of a single pendulum, let us now examine the vibrations of a double pendulum, giving two vibrations at once. The little copper ring *r*, in Fig. 12, on the cord of our pendulum, will slip up and down, and by moving it in either direction we can combine two pendulums in one. Slide it one-quarter way up the cord, and the double cord will be drawn together below the ring.

Now, if we pull the bob to the right or left, we can make it swing from the copper ring just as if this point were a new place of support for a new pendulum. As it swings, you observe that the two cords above the ring are at rest. But the upper pendulum can also be made to swing forward and backward,

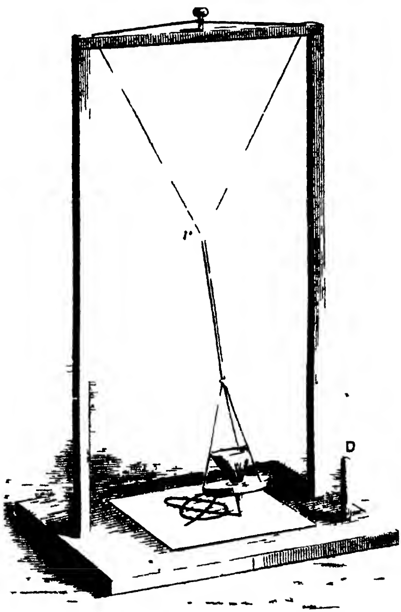


FIG. 12.

and then we shall have two pendulums combined. Let us try this and see what will be the result.

Just here we shall find it more convenient to use the metric measure, as it is much more simple and easy to remember than the common measure of feet and inches. If you have no metric measure you had best buy one, or make one. Get a wooden rod just $39\frac{37}{100}$ inches long, and divide this length into

100 parts. To assist you in this, you may remember that 1 inch is equal to $25\frac{4}{10}$ millimetres. Ten millimetres make a centimetre, and 100 centimetres make a metre.

Now slide the ring *r*, Fig. 12, up the cords till it is 25 centimetres from the middle of the thickness of the bob. Then make it exactly 100 centimetres from the under side of the cross-bar to the middle of the thickness of the bob, by turning the violin-key on the top of the apparatus.

At *D*, Fig. 12, is a small post. This post is set up anywhere on a line drawn from the centre of the platform, and making an angle of 45° with a line drawn from one upright to the other. Fasten a bit of thread to the string on the bob that is nearest to the post, and draw the bob toward the post and fasten it there. When the bob is perfectly still, fill the funnel with sand, and then hold a lighted match under the thread. The thread will burn, and the bob will start off on its journey. Now, in place of swinging in a straight line, it follows a curve, and the sand traces this figure over and over.

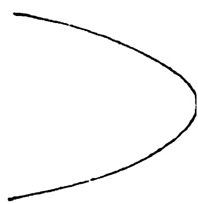


FIG. 13.

Here we have a most singular result, and we may well pause and study it out. You can readily see that we have here two pendulums. One-quarter of the pendulum swings from the copper ring, and, at the same time, the whole pendulum swings from the cross-bar. The bob cannot move in two directions at the same time, so it makes a compromise and

follows a new path that is made up of the two directions.

The most important fact that has been discovered in relation to the movements of vibrating pendulums is that the times of their vibrations vary as the square roots of their lengths. The short pendulum below the ring is 25 centimetres long, or one-quarter of the length of the longer pendulum, and according to this rule it moves twice as fast. The two pendulums swing, one 25 centimetres and the other 100 centimetres long, yet one really moves twice as fast as the other. While the long pendulum is making one vibration the short one makes two. The times of their vibrations, therefore, stand as 1 is to 2, or, expressed in another way, 1 : 2.

EXPERIMENT 14.—Let us try other proportions and see what the double pendulum will trace. Suppose we wish one pendulum to make 2 vibrations while the other makes 3. Still keeping the middle of the bob at 100 centimetres from the cross-bar, let us see where the ring must be placed. The square of 2

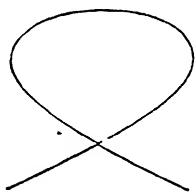


FIG. 14.

is 4, and the square of 3 is 9. Hence the two pendulums of the double pendulum must have lengths as 4 is to 9. But the longer pendulum is always 1,000 millimetres. Hence the shorter pendulum will be found by the proportion 9 : 4 :: 1,000 : 444·4 millimetres. Therefore we must slide the ring up the cord till it is 444·4 millimetres above the middle of the thickness of the bob.

	Mm.	Mm.	
1 : 2 =	1,000 :	250·0	Octave.
2 : 3 =	1,000 :	444·4	Fifth.
3 : 4 =	1,000 :	562·5. .	Fourth.
4 : 5 =	1,000 :	640·0.	Major Third.
5 : 6 =	1,000 :	694·4 .	Minor Third.
6 : 7 =	1,000 :	734·6 .	Sub-Minor Third.
7 : 8 =	1,000 :	765·6.	Super Second.
8 : 9 =	1,000 :	790·1 .	Second.

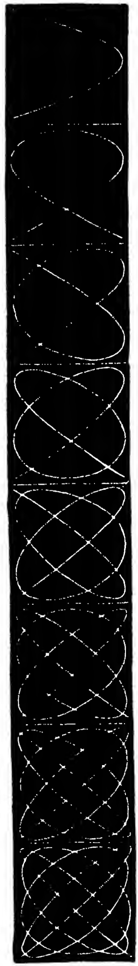


FIG. 15.

Fasten the bob to the post as before, fill it with sand, and burn the thread, and the swinging bob will make this singular figure (Fig 14).

EXPERIMENT 15.—From these directions you can go on and try all the simple ratios, such as 3 : 4, 4 : 5, 5 : 6, 6 : 7, 7 : 8, and 8 : 9. In each case raise the two figures to their squares, then multiply the smaller number by 1,000, and divide the product by the larger number; the quotient will give you the length of the smaller pendulum in millimetres. Thus the length for rates of vibration, as 3 is to 4, is found as follows: $3 \times 3 = 9$, $4 \times 4 = 16$, and

$$\frac{9 \times 1000}{16} = 562{\cdot}5 \text{ millimetres.}$$

The table (Fig. 15) gives, in the first and second columns, the rates of vibration, and in the third and fourth columns the corresponding lengths of the longer and shorter pendulums. Opposite these lengths are the figures which these double pendulums trace. In the sixth column are the names of the musical intervals (*see* page 34) formed by two notes, which are made by numbers of sonorous vibrations, bearing to each other the ratios given in the first and second columns.

FIXING THE CURVES ON GLASS.

EXPERIMENT 16.—These interesting figures, traced in sand by the double pendulum, may be fixed on glass in a permanent form; and, when framed, will make beautiful ornaments for the window or mantle-piece, and remind you that you are becoming an experimenter. Procure squares of clear glass about six inches on the sides, and buy at the painter's a small quantity of French varnish, or clear spirit-varnish. Hold one of these pieces of glass level in the left hand by one corner, and, with the right, pour

D 2

some of the varnish upon the glass. Let the varnish cover half the glass, and then gently tip the glass from side to side till the varnish runs into every corner; then tip it up, and rest one corner in the mouth of the varnish-bottle, and rock the glass slowly from side to side. This will give a fine smooth coat of varnish to the glass, and we may put it away to dry. When the varnish is hard, lay the glass, varnished side up, on the stand, adjust the pendulum to make one of the figures, and then fasten it to the post. Burn the thread, and stop the motion of the bob as soon as the figure is finished. Brush away any extra sand that may lie at the ends of the figure, and then take the glass carefully to a hot stove. Have some wooden blocks laid on the stove, and rest the glass on these. Presently the varnish will begin to melt, and then the glass may be lifted and carefully put away to cool, taking the utmost care not to disturb the sand. When the varnish is hard, the sand which has not stuck is removed by gently rapping the edge of the plate on the table. Then we shall have a permanent figure of the curve. To preserve it, lay small pieces of cardboard at each corner and narrow strips half-way along the edges, and then lay another piece of glass over these, and bind the two together with paper on the edges. The plate may now be placed on the lantern, and greatly magnified images of the curve may be obtained on the screen.

EXPERIMENTS IN WHICH WE COMBINE THE MOTIONS OF TWO VIBRATING RODS.

We have just seen how the double pendulum combines into one movement the motions of two pendulums swinging at right angles to each other. Our experiments have also taught us that the numerical relation between the numbers of swings

of the two pendulums is shown by the curved figure produced; so that, knowing the figure, we can tell the relative number of vibrations of each pendulum, and, from knowing the latter, we can predict the curved figure that the double pendulum will draw. But our experiments have taught us that a vibrating

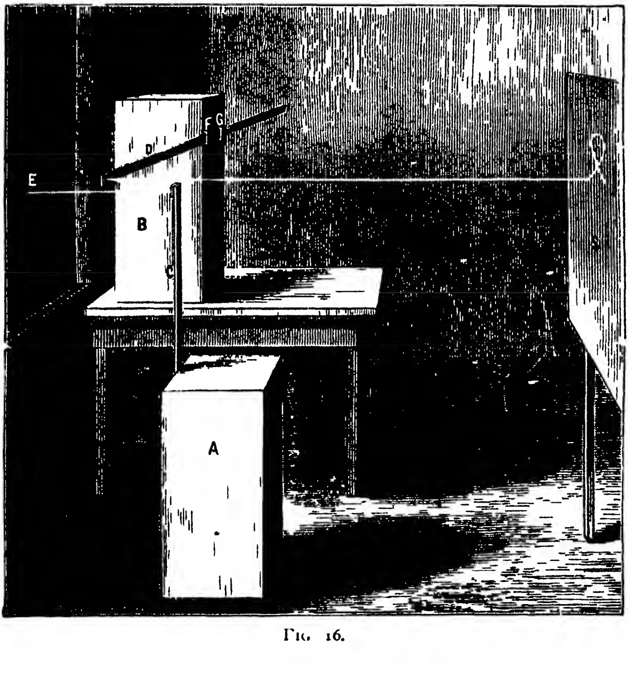


FIG. 16.

rod moves to and fro with the same kind of motion as a swinging pendulum. From this it follows that if by any means we can combine into one motion the separate motions of two vibrating rods, we shall make these rods describe the curved figures traced by the double pendulum.

The motions of two vibrating rods may be combined into one motion by means of a beam of light, which, falling on a mirror fastened to the end of one rod, is reflected to a mirror fastened to the end of the other rod, while from this second mirror the beam is reflected to a screen.

It is absolutely necessary for the success of these experiments that the vibrating rods should be fastened to bodies which are heavy and firm, and do not vibrate when the rods are set in motion. Boxes *A* and *B* of Fig. 16, about 14 inches square, half filled with sand, gravel, or dry earth, make such supports. The rods *C* and *D* are of clear, white pine, 4 feet (121·9 centimetres) long, 1 inch (25 millimetres) wide, and $\frac{1}{4}$ inch (6·25 millimetres) thick. On the end of each rod is fastened with wax a silvered glass mirror, 1 inch square. The upright rod *C* is fastened to the side of the box *A* by two screws, which go through the rod and into the box near the edge of its top. Another screw fastens the rod to the box at a distance of several inches below the upper screws. The free end of this rod, above the box, is exactly 30 inches (76·2 centimetres). The length of the horizontal rod *D* can be changed at will, for it is clamped to the side of the box *B* by screws, which go through the ends of the two pieces of wood *F* and *G*. Two nails are driven into the box under this rod, and serve to guide it in a horizontal direction while we slide it out or in. A piece of paper, 1 inch square, with a hole in its centre of $\frac{1}{4}$ inch in diameter, is pasted on the mirror of the rod *C*.

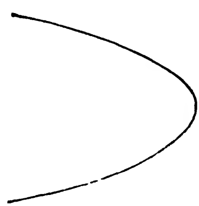
EXPERIMENT 17.—To begin the experiment, we place the heliostat in the window. The box *A* has been made of such a height that, when placed before the window, the centre of the mirror is opposite the centre of the opening *E* in the heliostat. We now loosen the screws in the clamps *F* and *G*, and slide the rod *D* under the clamps till it projects beyond the box exactly $20\frac{7}{16}$ inches (51·91 centimetres). The

boxes *A* and *B* are now placed in such positions that the light, falling on the ¼-inch circle on the mirror of the rod *C*, is reflected to the square-inch mirror on the rod *D*, and thence is reflected to a white screen *S* at the other end of the room, on which it appears as a little bright circle.

In Fig. 16 the bright lines show the light coming from the heliostat *E* to the mirror on the rod *C*, then going to the mirror on the rod *D*, to be reflected by it to the screen *S*.

Now pull toward you the rod *C*, and let it go. At once the bright circle on the screen is drawn out into a vertical line. As the width of the swings of the rod become less and less, the line becomes shorter and shorter, and finally contracts to the little bright circle when the rod has ceased to vibrate. Now pull aside the rod *D*, and let it go. The little circle on the screen is now drawn out into a horizontal line.

These two motions of the spot of light are at right angles to each other, and are exactly like the motions of the two pendulums of the double pendulum.



Hence, if both rods should vibrate at the same time, we should see the circle of light thrown into one of the familiar curved traces of the double pendulum. Let us try the experiment. Pull both rods aside, and let them go at the same instant. At once

the little circle vanishes from the screen, and there appears in its place this figure (Fig. 17). We at once recognise it as the same figure which the double pendulum drew in sand when one of its pendulums made two swings while its other pendulum made one. Therefore, one of these rods swings twice while the other swings once.

It may be that the figure on the screen is not stationary, but appears to twist and untwist itself with a sort of revolving motion. If it does so, it will go through curious changes. The horns of the above figure will split open at their ends, as shown at *B* in Fig. 18, and while they open more and more

A *B* *C* *D* *E*

FIG. 18.

they bend more and more into a line with each other, until the figure is like an 8, as at *C*. Then the 8 bends in its middle to the right, as in *D*, while its openings close up more and more, until the figure *A* again appears at *E*, but with the horns pointing to the right instead of to the left. Thus the figure changes, becoming smaller and smaller, till it vanishes into the circle of light from which it sprang.

By drawing the rod *D* in or out, or by loading it, or the rod *C*, with a lump of wax, the figure (17) may be made stationary as long as the rods vibrate; and, when this has been done, we know that one of the rods makes one vibration while the other makes exactly two; for the twisting and untwisting of the figure are caused by one of the rods making slightly more or less than one vibration while the other makes two.

Indeed, so delicate is this method of tuning one vibrating body with another, that it is used as the most precise one known to bring two tuning-forks to any required ratio in their vibrations. Hence these figures are sometimes called "the acoustic curves." In testing these forks, they are placed, like the rods, with their prongs at right angles, and the light is reflected from their polished prongs, as is shown in Fig. 16. Then, with a file, some of the metal of one of the forks is removed, either from the ends or the base of its prongs, till the figure on the screen remains stationary.

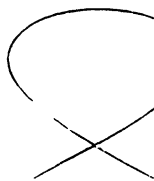


Fig. 19.

EXPERIMENT 18.—The rod *D* is now unclamped, and slid out till $24\frac{3}{16}$ inches (61·38 centimetres) of its end project beyond the edges of the clamps and box. The clamps are again screwed tightly against the rod. Now, on vibrating the rods together, we have on the screen the figure corresponding to the ratio 2 : 3, given in Fig. 19.

EXPERIMENT 19.—Making the experiment with the free length of the rod *D*, of $25\frac{5}{8}$ inches (65·09 centimetres), the figure on the screen is like that opposite the ratio 3 : 4 of Fig. 15.

EXPERIMENT 20.—Giving the rod *D* $26\frac{1}{4}$ inches (66·7 centimetres) of free vibrating end, it makes with the rod *C* the figure opposite the ratio 4 : 5 in Fig. 15. showing that one rod makes 4 vibrations in the time that the other makes 5.

You may not succeed the first time in getting these figures from the directions I have given. This is because the pine rods which you use may have different elasticities and weights from those which gave us the lengths we have put in this book. But, by drawing out or pushing in the rod *D*, you will, after the expenditure of a little patience, find the lengths of the rod *D* which give the desired figures. When found, these lengths should be preserved by drawing a lead-pencil across the rod along the outer edge of the clamp *F*. These marks will serve you when you wish to repeat these experiments before your friends. A piece of wax will assist you in getting the right lengths of the rod *D*. Stick the piece of wax on one of the rods. If the figure on the screen becomes more quiet, this shows that this rod which carries the wax should be lengthened. If the wax shows that the rod *C* should be lengthened, then we shorten the rod *D*, because the rod *C* always remains of the same length.

THE WAY TO DRAW THE ACOUSTIC CURVES.

By the aid of Fig. 5 we explained how one can plot on a line, *A B*, the distances that a pendulum goes through in equal small portions of time, by drawing perpendiculars to the line *A B* from the points of equal division of the circumference of the circle above it. In Fig. 5, if we assume that the pendulum goes from *A* to *B* in one second, then it goes through each of the divisions on the line *A B* in one-eighth of a second.

The above mode of getting the distances the pendulum goes over in successive small portions of time will serve us to draw at our leisure all the acoustic curves given by Blackburn's double pendulum, or by the two vibrating rods.

For example, suppose we wish to draw the figure

which is made when the two pendulums of the double pendulum, or the two rods in our last experiment, vibrate in the ratio of 4 to 5; that is, when one pendulum or rod makes 4 vibrations while the other pendulum or rod makes 5.

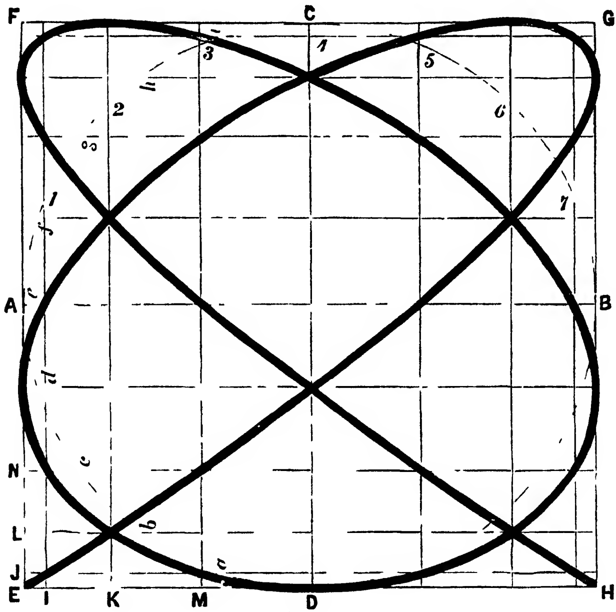


FIG. 20.

Draw the circle *A C B D*, Fig. 20, and inclose it in a square. Then draw the two diameters *A B* and *C D* parallel to the sides of the square. Divide the half-circumference *A C B* into 8—that is, twice 4—equal parts, and through the points of these divisions, 1, 2, 3, 4, 5, 6, 7, draw lines parallel to the diameter *C D*. Now turn the square round so that the diameter *C D* runs right and left. Then divide the half-circumference *D A C* into 10—that is, twice 5—equal

parts, and through the points of these divisions, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, draw lines parallel to the diameter *A B*. By these operations we have drawn a network of lines in the square *E F G H*. The spaces on the line *E H*, or on any line parallel to it, show how far one pendulum or vibrating rod moves in equal times. Let us suppose these times eighths of a second. The spaces on the line *E F*, or on any line parallel to it, show how far the other pendulum or rod moves in successive eighths of a second. Now let us begin at the corner *E*, and suppose that the point of the funnel of the double pendulum is over this corner. Where will the point of the funnel be at the end of the first eighth of a second? By the motion of one pendulum it will have moved from *E* to *I*, and by the motion of the other pendulum it will have moved from *E* to *J*. Therefore, at the end of the first eighth of a second, the point of the funnel will be where the lines drawn through the points *I* and *J* meet. For a like reason, at the end of the second eighth of a second, the pendulum-bob is at the point of meeting of the two lines drawn through the points *K* and *L*. It now at once appears how to draw the figure. Begin at the corner *E*, and draw a line to the opposite corner of the little parallelogram *J E I*; then continue the line to the next diagonally opposite corner, always passing diagonally from corner to corner of the successive parallelograms. Never leave any parallelogram, save at the corner, and you will end by tracing the complete figure, and then you will find the point of your pencil in the corner *H*.

In like manner, the curves corresponding to any given ratio of vibrations may be drawn. The formation of these curves is a very fascinating occupation. After you have gone over one with a lead-pencil, you may widen the line with a drawing pen, or a camel's-hair pencil dipped in Indian-ink. If you should hang up in your room these evidences of your progress in the art of experimenting, no one will call you vain.

EXPERIMENT 21.—One more experiment, and we will begin the study of vibrations giving sound.

Draw one of the acoustic curves in a square of 3 inches on a side, and place the figure so that its centre is directly under the point of the funnel of the double pendulum when this is at rest, and see that the sides of the square are parallel to the edges of the base-board of the pendulum.

The double pendulum having been accurately adjusted to trace the figure under it, draw the bob aside so that the point of its funnel is exactly over the corner of the square containing the figure. Pour sand in the funnel, and burn the thread. The pendulum starts on its journey, and as it goes it really seems guided in its motion by the figure under it, for it strews the sand over its lines in the most precise manner; showing again, very neatly, that the motion of a pendulum is indeed very accurately reproduced by looking at a ball in the plane of the circle around which it uniformly revolves.

CHAPTER V.

ON A VIBRATING SOLID, LIQUID, OR GASEOUS BODY BEING ALWAYS THE ORIGIN OF SOUND.

IN this chapter it is shown that the mechanical actions, which finally result in giving us the sensation of sound, always have their origin in some vibrating body, and that this vibrating body may be either solid, liquid, or gaseous.

EXPERIMENTS WITH A TUNING-FORK.

At the music-dealer's buy two forks marked "Philharmonic A." These two forks must be rigorously in tune with one another. Buy also another fork marked "Philharmonic C." For the present we only need one of the A-forks; the others will be used in future experiments.

EXPERIMENT 22.—Get a match, and spreading two of your fingers apart rest it upon both. Hold the fork in the right hand, and strike the end of one prong squarely and smartly on the knee, or on a piece of thick paper folded over the edge of the table. Now bring the fork up under the match. The instant the match is touched it flies into the air as if knocked away by a sudden blow.

EXPERIMENT 23.—Fill a tumbler brimful of water, and, starting the fork once more, hold it over the water so that the ends of the prongs touch the surface; immediately two tiny showers of spray will fly off on either side. This makes a startling experiment when

seen magnified upon the screen (*see* "Light," page 79). A blow struck on the match, and the water dashed violently out of the glass, show that the tuning-fork is in motion, that it vibrates or quivers when it is struck. Strike it once more and bring it to the ear, and you hear a clear sound, a smooth and pleasant musical note. We conclude that the motion must be the cause of the sound, for the sound ceases when the fork ceases to quiver.

EXPERIMENT 24.—Put a small piece of wax against the broad face of the end of a prong of the fork, and stick against this wax the flat head of a tack. The point of the tack should be slightly rounded by a file. Place a piece of tinfoil on a napkin or piece of cloth, then vibrate the fork and draw the point of the tack quickly along the surface of the foil. The series of dots now seen on the foil show that the prong moved to and from the foil as you drew the fork over its surface.

EXPERIMENT 25.—Fig. 21 represents a square block of wood made by nailing several pieces of board of the same size one upon the other. At one side, near the bottom, is the tuning-fork driven into a hole in the block, so that it will be supported in a horizontal position about ¼ inch (6 millimetres) from the table. A slender triangular bit of tinsel is fixed with wax on the end of one of the prongs to serve as a pen. To make the fork sound in this position we need a hammer or drumstick, made by slipping a piece of rubber tubing over a stout wire. It is, however, always better to vibrate a fork by drawing a violin-bow over one of its prongs.

Get a piece of clean glass 3 inches (7·6 centimetres) wide and about 8 inches (20·4 centimetres) long. Smoke this on one side with the apparatus described in Experiment 12, and then slip it, smoked side up, under the tuning-fork, lifting the fork so that the tinsel-pen on its end will not touch the glass. Next, lay a straight strip of wood, *A B*, Fig. 21, beside the glass

and fasten it down with brads. This is to serve as a guide in sliding the plate under the fork.

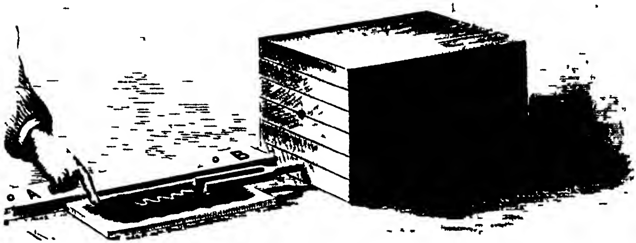


FIG.

Bend the tinsel-pen down so that it just touches the glass. While the fork is vibrating, slide the glass quickly along the guide, taking pains to move it at the same speed all the time.

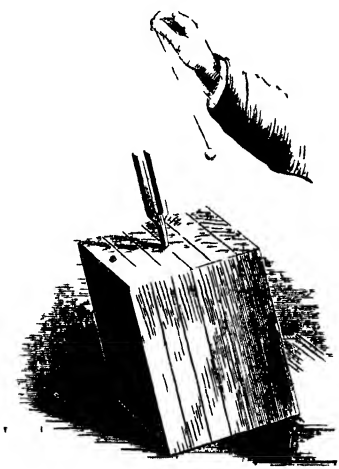
Hold the glass up to the light, and you will see a delicate wavy line, a sinusoidal trace. We cannot see the minute movements of the fork, yet here we have a picture of these movements. We see and readily read and understand its own handwriting. Placed in the water-lantern, this trace made by the fork may be exhibited on a magnified scale before many persons. To preserve this autograph of the fork, flow spirit-varnish over the smoked side of the glass, and then the picture may be handled without injuring it.

You must have observed that the fork gave a clear musical sound; and here we must make a distinction between a musical sound and mere noise. A noise is also a sound, but an irregular sound. It also is caused by vibrations, but the vibrations are irregular, now fast, now slow, confused and disordered. A musical sound is always caused by vibrations, simple

or compound, which regularly repeat themselves, like those of the tuning-fork which you have just examined. For convenience, we will call all sounds made by regular vibrations "sounds." All of our experiments will have to do with musical sounds, and will finally lead to music itself.

EXPERIMENT WITH A VIBRATING TUNING-FORK AND A CORK BALL.

EXPERIMENT 26.—Fig. 22 represents the fork inclined by placing a book under one edge of the block. Cut a small ball, about the size of a pea, out of cork,



and dip it in spirit-varnish; when dry, fasten it to a fibre of fine floss silk. Take the end of the fibre in the left hand so that the ball will hang free, and then

with the hammer in the right hand strike the fork a smart blow. At once bring the ball to rest against the foot of the prong, just above where it joins the handle. Here the ball rests quiet against the fork. Now slowly raise the ball, keeping it close to the fork. Immediately it begins to tremble. Raise it higher, and it darts away in little jerks and jumps. Lift it higher, and it becomes still more agitated, and near the end of the fork it is dashed violently away, as shown in Fig. 22; it falls back and is dashed away again.

Now take the fork out of the block, and bring the end of its handle against the cork ball. The ball trembles. These experiments show that there are places of rest above the crotch of the fork, and that the prongs swing to and fro about these places of rest, while the handle, or foot of the fork, vibrates up and down. Experiment 60 will teach us yet more as to the manner in which the prongs vibrate. In the above experiments, a small bead, hung by the silk fibre, sometimes works as well as the cork ball.

EXPERIMENTS WITH A BRASS DISK.

At the hardware-shop you can buy a piece of sheet-brass $\frac{1}{8}$ inch (3 millimetres) thick and 6 inches (15 centimetres) square. Take care to get a flat piece, and, if it is not perfectly flat, have it hammered out flat at the brass-worker's. Then let the brass-worker cut it into a circle. Let him round off the edges, and cut a hole just $\frac{3}{16}$ inch (5 millimetres) in diameter in its centre. If the brass disk has been hammered, put it in a stove till it is red hot, and then take it out and lay it away where it will cool slowly. Cut about 6 inches (15·2 centimetres) from a rake or broom handle, and set it upright and firm in a heavy block of wood. With a knife pare off the sharp edges at the top of this upright, and then fit a screw tightly

to the hole in the brass disk, and screw the disk to the top of the upright. We have now a flat disk of brass resting firmly on a stout upright support.

EXPERIMENT 27.—Draw a violin-bow carefully over the edge of the disk, and after a little practice you will be able to make the disk give a clear, strong sound. The bow, alternately catching and slipping on the edge of the disk causes it to vibrate, and the vibrations result in sound. To make these vibrations visible, get some of the sand we used in the sand-pendulum, and scatter it thinly over the disk. Now, when the violin-bow causes the disk to vibrate, the sand will be agitated. Each grain will spring up and down with a curious, dancing motion. This movement of the sand shows that the disk is violently agitated; is beating up and down, and tossing the sand about at every vibration.

EXPERIMENT 28.—Touch one finger on the edge of the disk, and draw the bow at a point one-eighth of the way round the disk, measuring from the finger. We now get a most singular result. The sand dances furiously about, as before, and immediately gathers in lines, which are two diameters at right angles, and one of the diameters starts from the point where the finger touches the disk, as is shown in *A* of Fig 23.

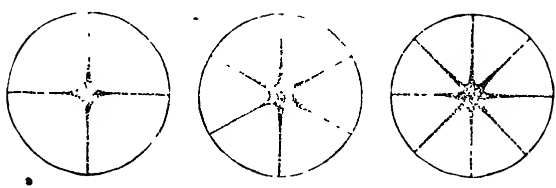


FIG 23.

EXPERIMENT 29.—Draw the bow at a point 30° distant from where the finger touches the disk, and 6 lines of sand will be formed, as at *B* in Fig. 23.

placed in this manner, will give an experiment showing that a liquid, like water, may vibrate and give a sound. If the flow of the water is carefully regulated, and the flute is of the right pattern, you will hear a low but distinct musical note from the water. Touch the glass jar and a piece of paper laid on the surface of the water, and you will feel them quivering with the vibrations. Here we have a flute blown by water under water, and giving a sound which is caused solely by the vibrations of the water. A queer flute, certainly, and an experiment as surprising in its effects as it is instructive.

PROFESSOR KUNDT'S EXPERIMENT, MADE WITH A WHISTLE AND A LAMP CHIMNEY, SHOWING THAT, AS IN WIND INSTRUMENTS, A VIBRATING COLUMN OF AIR MAY ORIGINATE SONOROUS VIBRATIONS.

EXPERIMENT 33.—The chimneys of student-lamps have a fashion of breaking just at the thin, narrow part near the bottom. Such a broken chimney is very useful in our experiments. At *A*, in Fig 25, is

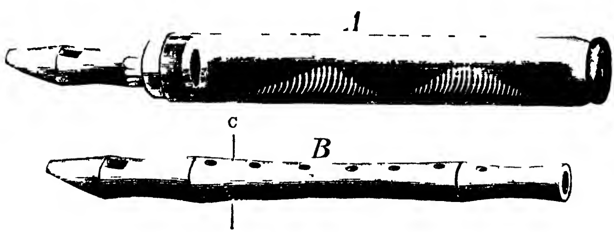


FIG. 25.

such a broken chimney, closed at the broken end with wax. A cork is fitted to the other end of the chimney, and has a hole bored through its centre. In this hole is inserted part of a common wooden whistle.

At *B* is an exact representation of such a whistle, and the cross-line at *C* shows where it is to be cut in two. Only the upper part is used, and this is tightly fitted into the cork.

Inside the tube is a small quantity of very fine precipitated silica, probably the lightest powder known. Hold the tube in a horizontal position and blow the whistle. The silica powder springs up into groups of thin vertical plates, separated by spots of powder at rest, as in the figure. This is a very beautiful and striking experiment.

EXPERIMENT 33 *a.*—The following experiment shows that the sound is caused by the vibrations of the column of air in the tube and whistle, and not by the vibrations of these solid bodies. Grasp the tube and whistle tightly in the hands. These bodies are thus prevented from vibrating, yet the sound remains the same.

The breath driven through the mouth of the whistle strikes on the sharp edge of the opening at the side of the whistle, and sets up a flutter or vibration of air. The air within the glass tube now takes part in the vibrations, the light silica powder vibrates with it, and makes the vibrations visible.

To exhibit this experiment before a number of people, lay the tube carefully on the water-lantern before the heliostat, and throw a projection of the tube and the powder on the screen. When the whistle is sounded, all in the room can see the fine powder leaping up in the tube into thin, upright plates.

EXPERIMENT 34.—Mr. Geyer has made the following pleasing modification of this experiment: Take a glass tube about 2 feet (61 centimetres) long and $\frac{3}{4}$ inch (19 millimetres) diameter. One end of this tube is stopped with a cork; then some silica is poured into it. The other end is placed in the mouth. Singing into the tube, a note is soon struck which causes the silica to raise itself in groups of

vertical plates, separated by places where the powder is at rest, the number of these groups and their positions in the tube changing with the note sung.

We have now seen how solids, like steel or brass, may vibrate and give a sound. We have heard a musical sound from vibrating water, and these last experiments prove that a gas, like air, may also vibrate and give a sound. In the next chapter you will find experiments which show how these vibrations move through solids, through liquids, and through the air.

CHAPTER VI.

ON THE TRANSMISSION OF SONOROUS VIBRATIONS THROUGH SOLIDS, LIQUIDS, AND GASES, LIKE AIR.

EXPERIMENT WITH A TUNING-FORK AND WOODEN ROD.

IN this chapter it is shown that a solid, a liquid, or a gas, like air, may conduct to a distant point the vibrations made at the place of origin of the sound.

EXPERIMENT 35.—Get the tuning-fork and one of the pine rods we used in Experiments 9 and 17. Let one hold the rod horizontally and lightly pressed against the panel of a door. Let another make the fork vibrate, and then press the end of its handle against the free end of the rod. At once the door-panel gives the note of the fork. Take the fork away from the end of the rod and the sound is no longer heard. Why the panel gives so loud a sound will be explained by other experiments. Just now we are merely observing the fact that the vibrations of the fork move through the rod to the door.

EXPERIMENT 36.—Hold the rod to the ear, and touch the fork to the other end, and the sound will be heard distinctly.

EXPERIMENT 37.—If you hold the rod in the teeth and close the ears the sound will be heard, showing that the vibrations of the fork travel through the rod, through the teeth, and through the bones of the head to the ear.

EXPERIMENT 38.—Touch the handle of the vibrating fork to the head and you will perceive the sound.

EXPERIMENT 39.—Open the mouth and place in it your watch, taking care that your teeth do not touch it, and take note of the force of the sound you hear. Now gently bite the watch, and note how distinctly the ticks are heard.

EXPERIMENT 40.—At the toy-shops you can buy a little instrument sometimes called the "lovers' telegraph," or "telephone." It consists of two short pieces of tin tube, each having a membrane fastened over one end, and a long piece of twine joining the two membranes. Let one boy hold the open end of one of the tins to his ear, and let another take the other tin to the distance at which the twine is pulled out tight. Then let him sound the fork and touch its foot to the tin; immediately the boy at the other end hears the note. The vibrations of the fork travel through the first tin and membrane, then along the twine to the other membrane and tin to the ear of the listener.

AN EXPERIMENT IN WHICH SONOROUS VIBRATIONS ARE SENT THROUGH WATER.

EXPERIMENT 41.—At the carpenter's procure two wooden boxes measuring on the outside $7\frac{3}{4}$ inches (19·7 centimetres) long, $3\frac{7}{8}$ inches (9·84 centimetres) wide, and $2\frac{1}{2}$ inches (6·4 centimetres) deep, using pine $\frac{1}{4}$ inch (6 millimetres) thick. In making these boxes, neither dovetailing nor nails need be used; they may be glued together. One end of the box is left open. Make the tuning-fork sound, and then hold it upright, resting the handle on the centre of the top of the box. You observe the sound is now very much louder. Why this is so will be shown by other experiments.

EXPERIMENT 42.—In Fig. 26 is the box. A tumbler filled with water is standing on the box. The tuning-fork stuck in a block of wood rests on

the water. Take the fork and block in the hand, and make the fork vibrate; then immediately plunge the block in the water as represented in the figure. At once you will hear the sound of the fork apparently coming out of the box. The vibrations of the fork pass through its handle to the block, and from

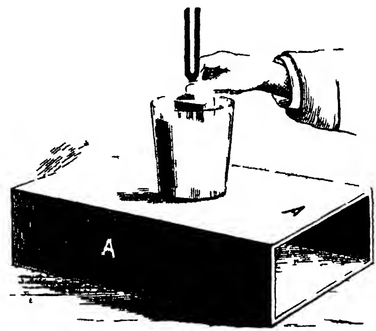


FIG. 26.

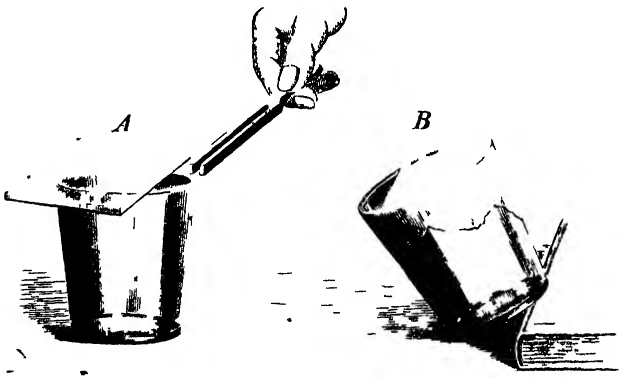
this through the water and through the bottom of the glass to the box. Our experiment thus shows that vibrations may easily pass through a liquid. A sheep's bladder filled with water may replace the tumbler and water in this experiment.

EXPERIMENTS SHOWING THAT THE AIR IS CONSTANTLY VIBRATING WHILE SONOROUS VIBRATIONS ARE PASSING THROUGH IT.

We must now add to our apparatus an open metal A-pipe, about $7\frac{1}{2}$ inches (19 centimetres) long, shown at *C* in Fig. 27. This pipe the organ-builder will accurately tune to your "A-philharmonic" fork.

EXPERIMENT 43.—Get a glass tumbler about $2\frac{1}{2}$ inches in diameter, and about $3\frac{1}{2}$ inches deep, though

any tumbler will do. Take a piece of window-glass about 3 inches square and place it over the tumbler. The glass must touch the edge of the mouth of the tumbler all round. Now slowly slide the glass so that the opening into the tumbler gets larger and larger, while the vibrating fork is held all the time



over this opening, as shown at *A* in Fig 27 Presently you will get an opening of a size that causes an intense sound, much louder than any you have ever before heard from the fork alone. This is because the air in the tumbler is set in vibration, and adds the vibrations of its mass to those of the fork. That this is so you may prove for yourself by the following experiment:—

EXPERIMENT 44.—Being careful not to move the glass plate from its present position (Experiment 43), stick it with wax to the tumbler. Pour a little silica

into the tumbler, and then hold it horizontally, and vibrate the fork near its opening, observing attentively how the silica powder is acted on by the inclosed vibrating air.

EXPERIMENT 45.—Take a piece of thin linen paper about 4½ inches square, and having wetted it paste it over the mouth of the tumbler. When the paper has dried it will be stretched tightly. Take a sharp penknife and carefully cut away the paper so as to make an opening as shown at *B* in Fig. 27. Make this opening small at first, and very gradually make it larger and larger. Hold the fork over the opening after each increase in its size, and you will soon discover the size of the opening which causes the air inclosed in the tumbler to vibrate with the fork, and thus greatly to strengthen its sound. You have now a mass of air in tune with the fork, and inclosed in a vessel which has one of its walls formed of a piece of elastic paper. With this instrument, which I have invented for you, you may make some charming experiments.

EXPERIMENT 46.—If the air in the tumbler vibrates to the A-fork, it will, of course, vibrate to the A-pipe, which gives the same note as the fork. Scatter some sand on the paper, and then sound the A-pipe a foot or two from it. The sand dances vigorously about, and ends by arranging itself in a nodal line parallel to the edges of the paper, in the form of a U with its two horns united by a straight line. The vibrations of the pipe can only reach the tumbler by going through the air, and, as the sand vibrates when the tumbler is placed in any position about the pipe, it follows that the air all round the pipe vibrates while the pipe is sounding.

EXPERIMENT 47.—Sprinkle a small quantity of sand on the paper, and then, placing a thin book under the tumbler, so incline it that the sand just does *not* run down the paper, as shown in *B*, Fig. 27. Now go to the farthest end of the room and blow the

pipe in gentle toots, each about one second long. At each toot, your friend, standing near the tumbler, will see the sand make a short march down the paper; and soon by a series of marches it makes its way to the edge of the paper and falls into the tumbler. I have, in a large room, gone to a distance of 60 feet (18·28 metres), and the experiment worked as I have just described it.

EXPERIMENT 48.—Again arrange the experiment as in Experiment 47, and standing three or four feet from the tumbler, try how feeble a sound will vibrate the paper. If every part of the experiment is in good adjustment, you will find that the feeblest toot you can make will set the sand marching. To keep it at rest you must keep silent.

EXPERIMENT 49.—To show these experiments on a greatly magnified scale, place the tumbler in front of the heliostat (*see* "Light," page 79) so that the sun's rays just graze along the inclined surface of the paper. Cut off a piece of a match $\frac{1}{8}$ inch long, and split this little bit into four parts. Place one of these on the inclined paper. Of course, the image of the tumbler is inverted, so the bit of wood appears to adhere to the lower side of the paper. If a little paper mouse cut out of smooth paper is used in place of the bit of wood, it is really amusing to see the mouse make a start to every toot of the pipe. I trust my reader will not think me unscientific for making a little fun. Singing the note A, instead of sounding it on the pipe, produces the same effects in the above experiments.

EXPERIMENT 50.—If you sing or sound some other note than the A, you will find it powerless to move the sand over the tumbler.

EXPERIMENT 51.—The experiments just made with the tumbler, partly covered with the glass plate or stretched paper, may be modified in a way that makes one of the most beautiful and instructive experiments.

• Take a pint bottle half filled with distilled or rain water, and put into it one ounce of shavings of white Castile soap; then shake the bottle. If the soap does not all dissolve, add more water till you have a clear solution. Then add a gill of glycerine, shake, and allow to settle. This solution is the best for making soap-bubbles.

Pour out the soap-solution into a basin; then dip the mouth of a deep tumbler (one 5 or 6 inches deep is the best) into it. The glass plate is now slid through the soap-water under the mouth of the tumbler. Take the tumbler, with the glass on it, out of the basin and stand it erect on the table. Vibrate the A-fork, and hold it over the edge of the tumbler while you slide the glass plate across its mouth, as we did in our other experiments. The opening which is thus made, between the rim of the tumbler and the edge of the glass plate, will have a soap-film over it. Adjust the size of this opening till it tunes the air in the tumbler to vibrate to the fork. When this takes place, a loud sound issues from the tumbler, and the delicate soap-bubble is violently agitated; its surface is chased and crinkled in so complicated a manner that its appearance cannot be described.

This experiment succeeds best with a very deep tumbler, like the one we have used, and with a C-fork and pipe. The soap-film covers nearly half of the mouth of the tumblei when the latter is in tune to the C-fork.

To see well the vibrating surface of soap-film, you must reflect from it the light of the sky.

EXPERIMENT 52.—By the aid of the heliostat and a lens the experiment may be made one of great beauty. With some wax stick the glass plate to the tumbler, so that the soap-film may be placed upright and inclined to the beam of light coming from the heliostat. With a plano-convex lens placed between the film and the screen you obtain a magnified image of the soap-film (*see* "Light," page 70).

As the soap-film is upright it drains thinner and thinner, while the image of the film grows more and more brilliant. Magnificent bands of reddish and bluish light appear, and stretch across the screen. Now sound the fork or pipe near the film. The vibrations bend and undulate the coloured bands, and the colours chase each other over the screen like waves on a troubled sea. On the sound ceasing, the bands straighten, and a comparative calm spreads over the screen.

EXPERIMENTS WITH THE SENSITIVE-FLAMES OF GOVI AND BARRETT, AND OF GEYER.

EXPERIMENT 53.—In Fig. 28, *A* is an upright wooden rod nailed to a block *D*. At *B* is a piece of

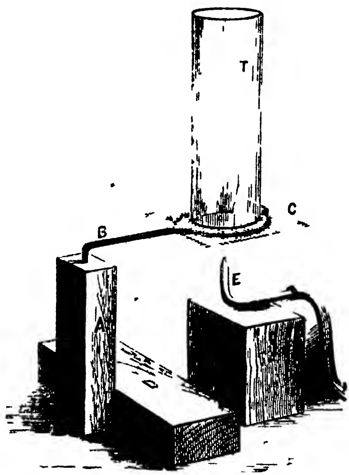


FIG. 28.

stout wire bent in the form of a ring, 5 inches (12·7 centimetres) in diameter, and then bent at a right

angle and stuck in the upright rod. On the ring is laid a piece of wire gauze that has about 30 meshes to the inch. *E* is a glass tube joined to a rubber tube that leads to the nearest gas-burner. To make this glass tube or jet, take a piece of glass tube, about ¼ inch outside diameter and 6 inches (15·2 centimetres) long, and, holding its ends in the hands, heat the tube, at about 1½ inch from its end, in a spirit-flame or the flame of a Bunsen burner till it softens; then pull it out till it is reduced about one-quarter in diameter. When it is cold, draw the edge of a file across this narrow part, and snap the tube asunder. Now heat in like manner the middle of this tube, and bend it into a right angle, as shown in Fig. 28, and, with wax, stick it upright on a block of wood, with the tip of the jet about 2 inches (5·1 centimetres) below the wire gauze.

Turn on the gas and light it above the gauze, where it will burn in a slender, conical flame, about 4 inches high, with its top yellow and its base blue. This forms the "sensitive-flame" invented by Prof. Govi of Turin, and afterward by Prof. Barrett of Dublin.

If you hiss, whistle, shake a bunch of keys, or clap the hands, the flame at once roars, and shrinking down to the gauze, becomes entirely blue and almost invisible. It is called a "sensitive-flame," because it is sensitive to sonorous vibrations, and shows us their existence in the air.

EXPERIMENT 54—Mr. Geyer, of the Stevens Institute of Technology, has made an addition to the Govi-Barrett flame, which heightens its sensitiveness, and makes it utter a musical note while disturbed by vibrations; while, in another modification of the experiment, the flame sings continuously, except when agitated by external sounds. I give his experiments in his own words:

"To produce them it is only necessary to cover Barrett's flame with a moderately large tube [*see* Fig. 28, in which, however, the tube is represented of somewhat too great a diameter], resting it loosely on the

gauze. A luminous flame, 6 or 8 inches long, is thus obtained, which is very sensitive to high and sharp sounds. If, now, the gauze and tube be raised, the flame gradually shortens, and appears less luminous, until at last it becomes violently agitated, and sings with a loud, uniform tone, which may be maintained for any length of time. Under these conditions, external sounds have no effect upon it. The sensitive musical flame is produced by lowering the gauze until the singing just ceases. It is in this position that the flame is most remarkable. At the slightest sharp sound, it instantly sings, continuing to do so as long as the disturbing cause exists, but stopping at once with it. So quick are the responses that, by rapping the time of a tune, or whistling or playing it, provided the tones are high enough, the flame faithfully sounds at every note. By slightly raising or lowering the jet, the flame can be made more or less sensitive, so that a hiss in any part of the room, the rattling of keys even in the pocket, turning on the water at the hydrant, folding up a piece of paper, or even moving the hand over the table, will excite the sound. On pronouncing the word 'sensitive,' it sings twice; and, in general, it will interrupt the speaker at almost every 's,' or other hissing sound.

"The tube chiefly determines the pitch of the note, shorter or longer ones producing, of course, higher or lower tones respectively. I have most frequently used either a glass tube, 12 inches long, and 1¼ inch in diameter, or a brass one of the same dimensions. Out of several rough pieces of gas-pipe, no one failed to give a more or less agreeable sound. Among these gas-pipes was one as short as 7 inches, with a diameter of 1 inch; while another was 2 feet long and 1¼ inch in diameter. A third gas-pipe, 15 inches long and ¾ inch in diameter, gave, when set for a continuous sound, quite a low and mellow tone.

"If the jet be moved slightly aside, so that the flame just grazes the side of the tube, a note somewhat lower than the fundamental one of the tube is produced. This sound is stopped by external noises, but goes on again when left undisturbed. All these experiments can be made under the ordinary pressure of street gas, ¾ inch of water being sufficient."

CHAPTER VII.

ON THE VELOCITY OF TRANSMISSION OF SONOROUS VIBRATIONS, AND ON THE MANNER IN WHICH THEY ARE PROPAGATED THROUGH ELASTIC BODIES.

ON THE SPEED WITH WHICH SONOROUS VIBRATIONS TRAVEL.

WHEN in the country, you have seen a man chopping wood. If you stood near him, you observed that the blow and the sound of his axe came together. If you moved away from him, you may have noticed that, while you could see his axe fall, and hear the sound of the blow, the sound seemed to follow the blow. When you moved away several hundred feet, the interval of time separating the sight of the blow and its sound was readily noted. You may also have observed that some time passed between the flash of a gun or the puff of a steam-whistle and the report of the gun and the sound of the whistle. These things convince us that sonorous vibrations take time to move through the air.

This matter has been carefully examined by scientific men, and they have found that sound-vibrations move through the air at the rate of 1,090 feet (332·23 metres) in one second. This is the velocity of sound when the temperature is just at freezing, or at 32° Fahrenheit. For each degree above this, sound gains in speed one foot more. For instance, upon a summer's day, the thermometer may stand at 80°. This is 48° above 32°, and the sound gains 48 feet, so that it moves at the rate of 1,138 feet a second at this temperature.

The velocity of sonorous vibrations in oxygen at 32° is 1,040 feet per second; in hydrogen gas it is 4,160 feet, just four times as great. As a cubic foot of hydrogen weighs 16 times less than a cubic foot of oxygen, and as 4 is the square root of 16, we gather that the speed of sonorous vibrations in gases varies inversely as the square roots of the weights of equal volumes of the gases.

Sonorous vibrations travel through water at the speed of 5,000 feet per second, and through iron at about 16,000 feet in a second.

EXPERIMENTS WITH GLASS BALLS ON A CURVED RAILWAY, SHOWING HOW VIBRATIONS TRAVEL THROUGH ELASTIC BODIES.

EXPERIMENT 55.—Fig. 29 represents a wooden railway about 6 feet (183 centimetres) long. It may be made of pine strips, $1\frac{1}{2}$ inch (3·8 centimetres) wide and $\frac{1}{4}$ inch (6 millimetres) thick, laid side by side about one inch (25 millimetres) apart, and joined together by short cross-strips nailed on them. Get six or seven large glass marbles at the toy-shop.

FIG. 29.

These are intended to roll between the two strips, just as balls roll in the railway of a bowling-alley. Place the railway on a table or board, and fasten it down at the middle with a screw in the cross-strip, and then raise each end and put a book or wooden block under it, as in Fig. 29.

Place the balls in the middle of the curving railway, and then bring one to the end and let it roll down against the others. Immediately the last ball will fly out and roll part way up the incline toward the other end of the railway. The first ball will come to

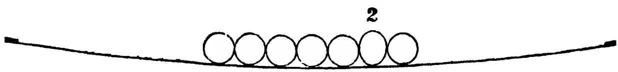


FIG. 30.

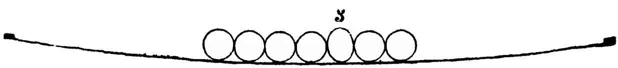


FIG. 31.

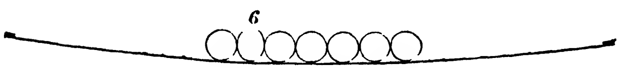


FIG. 32.

rest beside the others, and the ball which has been shot up the railway will roll back against those at rest, and the same performance will be repeated till the motion has gone from the rolling balls.

Let us examine this matter, and see what happens to these balls on the railway. First, you must observe that the balls are elastic, for experiment will show that they will bound like rubber balls when let fall on the hearth-stone.

EXPERIMENT 56.—To show that the ball is elastic, and *flattens* when it strikes the stone, make the following experiment: Mix some oil with a little red-lead, or other coloured powder, and smear it over a flat stone, like a flag-stone. Rest the ball on this, and observe the size of the circular spot made on it. Now let the ball fall on the stone, and observe the larger circular spot made by the fall. This shows

that when the ball struck it flattened and touched a larger surface on the stone.

The first ball rolls down and strikes a hard blow on the side of ball No. 2. This ball is flattened between balls Nos. 1 and 3, as shown in Fig. 30.

Ball No. 2 at once springs back again into its former spherical figure, and in doing so it brings No. 1 to rest and flattens No. 3, as shown in Fig. 31.

Ball No. 3 now springs back in to its spherical form, and in doing so acts on No. 2. and brings it to rest, and acts on No. 4 and flattens it. Thus each ball passes the blow on to the next by its elasticity, and each in turn flattens and then springs into its natural form, and thus we have a series of contractions and expansions running through the whole series of balls. The last ball is finally flattened, and, when it expands immediately afterwards, it presses against the ball that gave it the blow and brings it to rest; at the same time, finding no resistance in front of it, its back-action on the ball behind it causes it to start up the railway. Thus the last ball, No. 7, is shot up the railway by a force derived from ball No. 1, and which was sent through all the balls by their successive contractions and expansions.

EXPERIMENTS WITH A LONG SPRING, SHOWING HOW VIBRATIONS ARE TRANSMITTED AND REFLECTED.

EXPERIMENT 57.—Obtain a brass wire, wound in the form of a spiral spring, about 12 feet long. Get an empty starch-box or cigar-box, and take off the cover, and then set it on one end at the edge of a wooden table, with the bottom of the box facing outward. Screw this box firmly to the table, and then screw a small iron or brass hook to the bottom of the box, as shown in Fig. 33. Slip over this hook the loop at the end of the long spiral spring. Hold

the other end of the spring in the hand, letting it hang loosely between the hand and the box Insert a finger-nail or the blade of a knife between the turns of the wire, near the hand, and pull the turns asunder Free the nail suddenly, and a vibration or shock will start and run from coil to coil along the whole spring and a loud rap or a blow will be heard on the box,

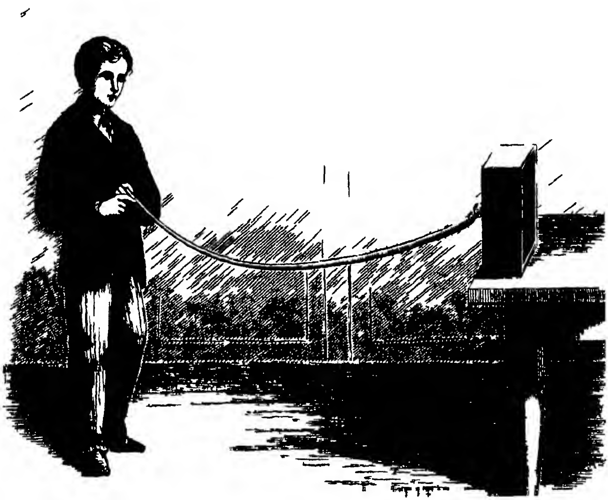


FIG 33.

thence to be reflected to the hand, and then again to the box, and so on Here we have a beautiful illustration of the manner in which a vibration may travel along an elastic substance, and make itself heard as a sound at the other end, there to be reflected back to the place whence it came, to begin over again its forward journey

EXPLANATION OF THE MANNER IN WHICH SONOROUS VIBRATIONS ARE PROPAGATED.

If the student clearly understands the actions in the experiments with the glass balls and spring-coil, he can have no difficulty in perceiving how a shock or vibration may in like manner pass through the elastic air.

For simplicity of illustration, imagine a very long tube, in which, at one end, fits a piston or plug. Suppose this piston moves quickly forward in the tube through a short distance—say, one inch—and then stops. If the air were inelastic, then one inch of air would move out of the other end of the tube while the piston moved forward one inch. But air is elastic; it *gives* before the motion of the piston; and it takes some time, after the piston has moved forward, before the air moves at the other end of the tube. If the tube is 1,100 feet long, and the temperature of the air 42°, it will be one whole second before the end of the air-column moves; for it takes that time for a sound vibration to traverse 1,100 feet, and a mechanical action on air of the above temperature cannot be sent through it with a greater speed than that

Now, suppose that the piston takes $\frac{1}{10}$ second to make its forward motion in the tube, how far will the air be compressed in front of it at the instant the piston stops? Evidently the answer is found by taking $\frac{1}{10}$ of 1,100 feet, which is 110 feet. If the piston takes $\frac{1}{100}$ of a second in moving forward, then at the end of that time the air is compressed before the piston to a depth of $\frac{1}{100}$ of 1,100 feet, or 11 feet. The length of the column of air, compressed by the forward motion of the piston, in every case is found by dividing the velocity of sound by the fraction of a second during which the piston was moving.

This compressed air cannot remain at rest in the tube, for it is now exactly like the compressed ball No. 2 of Fig. 30. It expands, and in expanding it acts backward against the immovable piston, but in front it compresses another column of air equal to it in length; this, in turn, acts like ball No. 3 of Fig. 31, bringing to rest the column of air behind it and compressing another column in front of it; and in this manner the compression will traverse a tube 1,100 feet long in one second.

If the piston moves backward in the tube, then a column of rarefied or expanded air will be formed in front of the piston, caused by the air expanding into the space left vacant by its backward motion; and this rarefaction will go forward through the air exactly as the compression did.

Now imagine the piston to move to and fro in the tube; it will send through the column of air condensations and rarefactions, following each other in regular order. If we have a body vibrating freely in the open air, it will form spherical shells of compressed and rarefied air all around it, these shells constantly expanding outward into larger and larger shells, and following each other in regular order and motion, like the regular movement of the circular water-waves which spread outward around a point of agitation on the surface of a pond. Thus the sound-vibrations are sent out in all directions from a vibrating body just as light is diffused in all directions around a luminous body. In our experiments in *Light*, page 23, we found that the illumination of a given surface varies in brightness inversely as the square of its distance from the source of light. In like manner the loudness of a sound decreases inversely as the square of our distance from the vibrating body. Thus, at 100 feet, the loudness of the sound is $\frac{1}{4}$ of what it was at 50 feet, and at 200 feet its loudness is $\frac{1}{16}$ of what it was when we were 50 feet distant.

Now what will be the effect on any portion of air—like that, for example, which touches the drum-skin of the ear—if these condensations and rarefactions reach it? Evidently, while the condensations are passing, the molecules (the smallest parts) of the air will move nearer each other, then regain their natural positions, to be separated yet farther by the rarefaction which follows at once. Therefore, the effect on any molecule will be to swing it to and fro. Hence the air, touching the drum-skin of the ear, moves forward and then backward, and forces the drum-skin in and then out. This swinging motion is conveyed to the fibres of the auditory nerve, and causes that sensation called sound.

But we have seen that vibrating bodies swing to and fro like the pendulum, hence those vibrating bodies which are causing sound make all the molecules of air around them swing to and fro like the bobs of very small pendulums, each pendulum beginning its swing just a little sooner than the one in front of it.

All this, however, and much more than we have time to write about, will be taught you very clearly by an instrument which I shall now show you how to make.

EXPERIMENTS WITH CROVA'S DISK, SHOWING HOW SONOROUS VIBRATIONS TRAVEL THROUGH AIR AND OTHER ELASTIC MATTER.

EXPERIMENT 58.—In Fig. 34 *A* is a cardboard disk mounted on a whirling machine or rotator *B*, and *C* is a piece of cardboard having a slit cut in it. Upon the disk are 24 eccentric circles drawn with a pen, and so placed that they can be seen through the slit in the cardboard. The rotator can be bought; the disk you can make yourself from the following directions: Get a piece of stiff cardboard, and cut

cut a disk 31 centimetres in diameter. In making this disk we will use the metric measure exclusively.

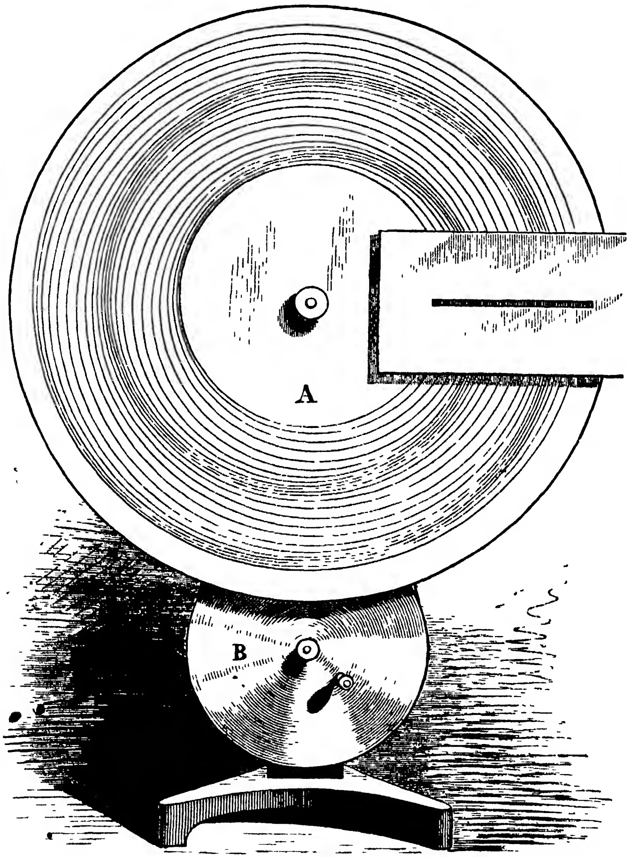
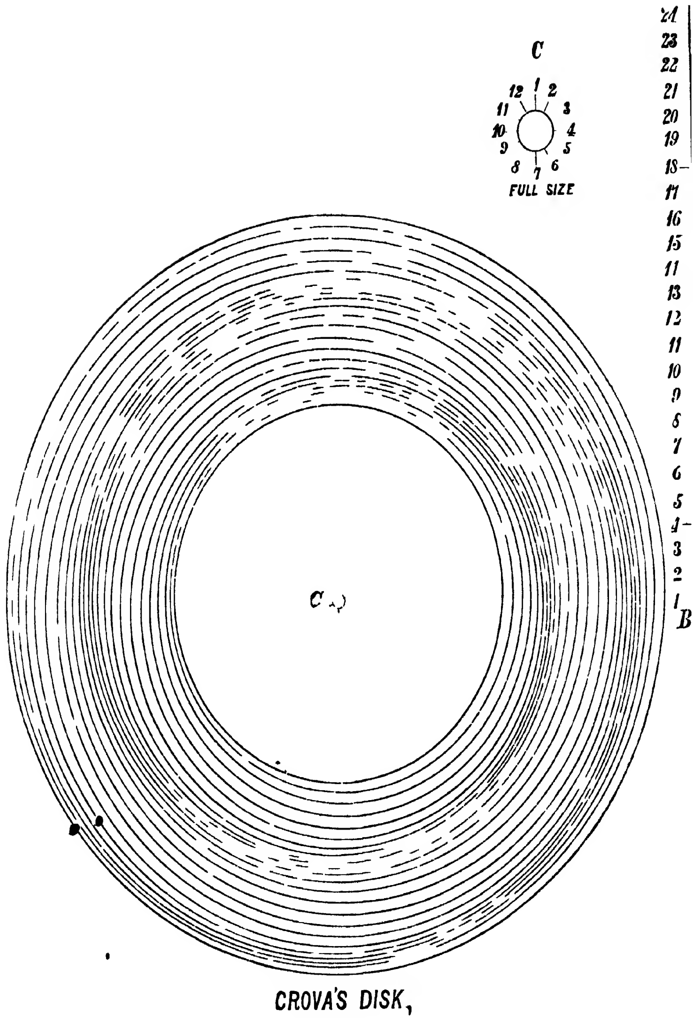


FIG. 34.

Round the centre *C* of this disk draw a circle just 5 millimetres in diameter. (*See C*, Fig. 35, where it

is drawn "full size.") Then divide this circle into 12 parts, and number the points of division 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12. The next step is to rule upon a sheet of paper a straight line $14\frac{1}{2}$ centimetres long, and to mark 72 millimetres of this off into 24 spaces of 3 millimetres each, as shown in the real size at *A B*, Fig. 35. This we use as a scale in spreading the dividers. Then draw a circle with the dividers spread $7\frac{1}{2}$ centimetres, from *A* to *B*, Fig. 35, using the dot No. 1 at the top of the circle *C* on the card-board as a centre. Then spread the compasses just 3 millimetres wider, using the scale we have just made for a guide, and make another circle, with dot No. 2 as a centre. You will observe that the two circles are eccentric—this is, they are not parallel to each other, one spreading a little to the right of the other. Go thus round the circle *C* twice, and use each dot in the circle in turn as a centre till you have 24 eccentric circles drawn on the disk, each circle having a radius 3 millimetres greater than the one next within it. When the circles are finished, ink them over with a drawing-pen holding violet ink, or Indian-ink. When dry, cut a small hole exactly in the centre, and mount the disk on the rotator. Get a piece of cardboard about 15 centimetres long, and cut in it a narrow slit about 10 centimetres long, in which the eccentric circles will appear like a row of dots when the cardboard is held before the disk, as in Fig. 34.

Now turn the handle of the rotator slowly and steadily. The disk will revolve, and the eccentric circles will move in the slit in the card. At once you have a most singular appearance. A horizontal, worm-like movement among the row of dots is seen in the slit. They crowd up against each other and then move apart, only to draw near again and then separate. There seems to be a wave moving along the slit, appearing at one end and disappearing at the other. At one part of the wave the dots are



CROVA'S DISK,
1/3D, SIZE.

crowding together, at another they are spreading apart. Look closely and you will observe that, although this wave appears to move over the length of the slit, yet each dot makes but a very small to-and-fro movement. No matter how fast the crank is turned, or how swiftly the waves chase each other along the slit, each dot keeps within a fixed limit, swinging to and fro as the waves pass.

We have learned that the prongs of a tuning-fork vibrate like a pendulum. Both prongs move, but just now we will only consider the motion of one. In vibrating it swings backward and forward, pushes the air in front of it, and gives it a squeeze; then it swings back and pulls the air after it. In this way the air in front of it is alternately pressed and pulled, and the molecules of air next to it dance to and fro precisely as the first dot swings to and fro behind the slit. You cannot see the motion of the molecules of air in front of the tuning-fork, yet our apparatus accurately represents their movements so that we can study them at leisure.

First comes an outward swing of the fork, and the air before it is squeezed or condensed. Then it swings back, and the air before it is pulled apart or spread out; in other words, it is rarefied. So it happens that the fork alternately condenses and rarefies the air. The air is elastic, and the layer nearest the fork presses and pulls its neighbours precisely as described in the previous section, where we explained the manner in which sonorous vibrations are propagated.

When the fork makes one condensation and one rarefaction, it has made one vibration; that is, it has swung once to *and* fro. Then it makes another vibration, and produces another condensation and rarefaction. Thus condensations and rarefactions follow each other, and move away from the fork in pairs, in regular order.

One condensation, together with its fellow rare-

faction, forms what is called a *sonorous wave.* If the fork, for example, should vibrate for exactly one second, and then stop, the air, for a distance of 1,100 feet all around it, will be filled with shells of condensed and rarefied air. Therefore, as one vibration to and fro of the fork makes one shell of condensed air and its neighbouring shell of rarefied air, we can find the combined thickness of these two shells by dividing 1,100 feet (the velocity of sound) by the number of vibrations the fork makes in one second. Our A-fork makes 440 vibrations in one second. Hence the depth of two shells—one of condensed, the other of rarefied air—formed by this fork is $1{,}100 \div 440$, which is $2\frac{1}{2}$ feet. The length thus obtained is called *a wave-length.* Evidently, the greater the number of vibrations a second the shorter the waves produced.

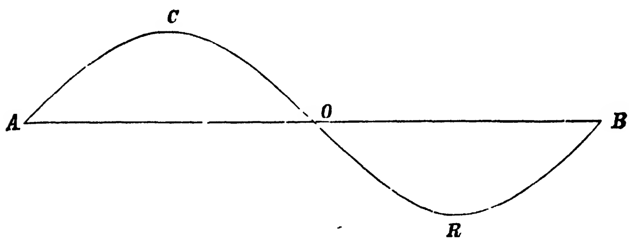


FIG. 36.

Scientific men, to represent a sonorous wave, always use a curve like *A C O R B* of Fig. 36, in which the part of the curve *A C O*, above the line *A B*, stands for the condensed half of the wave, while the part *O R B*, below *A B*, stands for the rarefied half of the wave, and the perpendicular height of any part of the curve *A C O*, above the line *A B*, shows the amount of condensation of the air at that part of the wave; while similar lines

drawn to the curve *O R B*, below *A B*, show the amount of rarefaction at these points of the wave.

The curve *A C O R B* is not a real picture of a sonorous wave; it is merely a good way of showing its length, and the manner in which the air is condensed and rarefied in it; for sonorous waves are not formed of heaps and hollows like the waves you have seen on the sea. They are not heaps and hollows of air, but only condensations and rarefactions of air. In short, Fig. 36 is merely a convenient *symbol* which stands for a sonorous wave.

EXPERIMENT 59.—Look at the row of dots seen in the slit when the disk is at rest, and find the two dots which are nearest to each other; this place in the slit corresponds to the point *C* in Fig. 36. Next find where the dots are farthest apart; this place corresponds to *R* in Fig. 36. The distance from *C* to *R* is one half wave-length; therefore the distance between two adjoining places, where the dots are nearest together, equals the length of one whole wave.

CHAPTER VIII.

ON THE INTERFERENCE OF SONOROUS VIBRATIONS AND ON THE BEATS OF SOUND.

EXPERIMENT 60.—Cut out two small triangles of copper foil or tinsel, of the same size, and with wax fasten one on the end of each of the prongs of a tuning-fork. Put the fork in the wooden block and set up the guide (as in experiment, Fig. 21). Prepare a strip of smoked glass, and then make the fork vibrate and slide the glass under it, and get two traces, one from each prong.

FIG 37.

Holding the glass up to the light you will see the double trace, as shown in Fig. 37. You observe that the wavy lines move apart and then draw together. This shows us that the two prongs, in vibrating, do not move in the same direction at the same time, but always in opposite directions. They swing toward each other, then away from each other.

EXPERIMENT 61.—What is the effect of this movement of the prongs of the fork on the air? A simple experiment will answer this question.

Place three lighted candles on the table at *A*, *B*, and *C* (Fig. 38). Hold the hands upright, with the space between the palms opposite *A*, while the backs of the hands face the candles *B* and *C*. Now move the hands near each other, then separate them, and

make these motions steadily and not too quickly. You thus repeat the motions of the prongs of the fork. While vibrating the hands observe attentively the flames of the candles. When the hands are coming nearer each other, the air is forced out from between them, and a puff of air is driven against the flame *A*, as is shown by its bending away from the

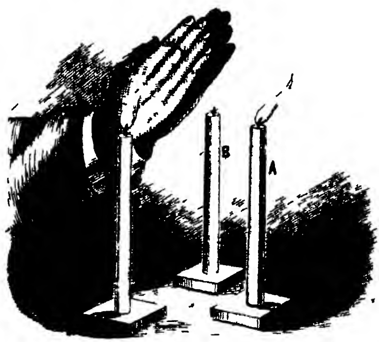


Fig. 38

hands. But, during the above movement, the backs of the hands have drawn the flames toward them, as shown in Fig. 38. When the hands are separating the air rushes in between them, and the flame *A* is drawn toward the hands by this motion of the air, while at the same time the flames at *B* and *C* are driven away from the backs of the hands. From this experiment it is seen that the spaces between the prongs and the faces of the prongs of a fork are, at the same instant, always acting oppositely on the air.

This will be made clearer by the study of the diagram, Fig. 39.

This figure supposes the student looking down on

the tops of the prongs of the fork. Imagine the prongs swinging away from each other in their vibration. Then the action of the faces *c* and *c* on the air is to condense it, and this condensation tends to spread all around the fork. But, by the same movement, the space *r r* between the prongs is enlarged, and hence a rarefaction is made there. This rarefaction also spreads all around the fork. But, as the condensations produced at *c* and *c* and

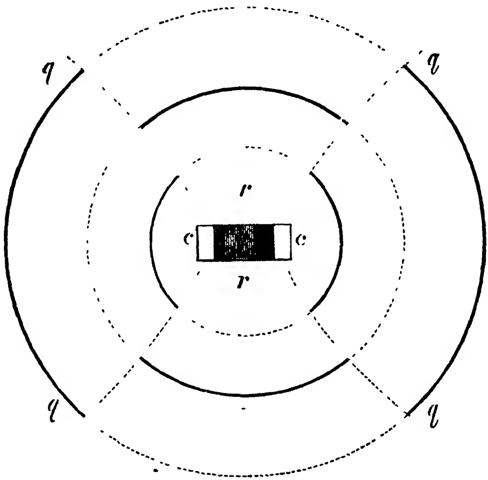


FIG 39.

the rarefactions at *r* and *r* spread with the same velocity, it follows that they must meet along the dotted lines *q*, *q*, *q*, *q*, drawn from the edges of the fork outward. The black ¼-circle lines around the fork in Fig. 39 represent the middle of the condensed shells of air, while the dotted ¼-circle lines stand for the middle of the rarefied shells of air.

Now what must happen along these dotted lines, or, rather, surfaces? Evidently there is a struggle

here between the condensations and the rarefactions? The former tend to make the molecules of air go nearer together, the latter try to separate them; but, as these actions are equal, and as the air is pulled in opposite directions at the same time, it remains at rest—does not vibrate. Therefore, along the surfaces *q*, *q*, *q*, *q*, there is silence. When the prongs vibrate toward each other they make the reverse actions on the air; that is, rarefactions are now sent out from *c* and *c*, while condensations are sent from *r* and *r*, but the same effect of silence along *q*, *q*, *q*, *q*, is produced.

EXPERIMENT 62.—That this is so, is readily proved by the following simple experiment. Vibrate the fork and hold it upright near the ear. Now slowly turn it round. During one revolution of the fork on its foot, you will perceive that the sound goes through four changes. Four times it was loud, and four times it was almost if not quite gone. Twirl the fork before the ear of a companion; he will tell you when it makes the loudest sound, and when it becomes silent. You will find that when it is loudest the faces *c*, *c* of the prongs, or the spaces *r*, *r* between them are facing his ear; and when he tells you that there is silence you will find that the edges of the fork, that is, the planes *q*, *q*, *q*, *q*, are toward his ear.

AN EXPERIMENT IN WHICH INTERFERENCE OF SOUND IS SHOWN BY ROTATING A VIBRATING FORK OVER THE MOUTH OF A BOTTLE RESOUNDING TO THE NOTE OF THE FORK.

EXPERIMENT 63.—Get a bottle, like one of those shown in Fig. 40, holding about five fluid ounces when filled to its brim. Its mouth should measure 1 inch (25 millimetres) in diameter. Cut a piece of glass $1\frac{1}{2}$ inch long and 1 inch wide, and slide this over the mouth of the bottle while the vibrating A-fork is

held over it. Fix the piece of glass with wax at the place where it makes the air in the bottle resound the loudest (*see* Fig. 40).

Again vibrate the fork, and holding it horizontally twirl it slowly over the partly closed bottle, just as we twirled it before the ear. You will find that whenever the corners of the fork have come opposite the mouth of the bottle the sound will have faded away to silence. In this position of the fork, one of the planes *q*, *q*, *q*, or *q*, of Fig. 39, goes directly down to the mouth of the bottle, and therefore there enter the bottle, side by side, at the same time, a condensation and a rarefaction. Hence the air in the bottle is acted on by two equal and opposed actions; it cannot vibrate to the fork, and we have rest and silence. The above experiment, and the following one, may be made with the tuned tumblers of Experiment 43 as well as with the bottles.

EXPERIMENTS IN WHICH INTERFERENCE OF SOUND IS OBTAINED WITH A FORK AND TWO BOTTLES.

EXPERIMENT 64.—Fig. 40 represents two glass bottles, of equal size, each tuned as described in Experiment 63. Set one bottle upright, and with two bits of wax hold the other horizontally on some books, with the mouths of the bottle nearly touching, as shown in Fig. 40.

Make the fork vibrate, and, holding it horizontally, bring it down so that the space between the prongs will be opposite the mouth of the upright bottle, as shown in Fig. 40. As it descends, you will observe that the sound first increases, and then suddenly fades away or entirely disappears. You can raise the fork and hear it still sounding, so that you may be sure it has not stopped, and yet, in a certain position between the two bottles, the sound is nearly if not wholly lost.

In this experiment, you will observe that while the face of one of the prongs is opposite the mouth of one bottle, the space between the prongs is opposite the mouth of the other bottle. Therefore, while one bottle receives a condensation the other receives a rarefaction. Thus opposed vibratory motions issue from the mouths of the bottles, and they neutralize each other's action on the outside air. Hence silence

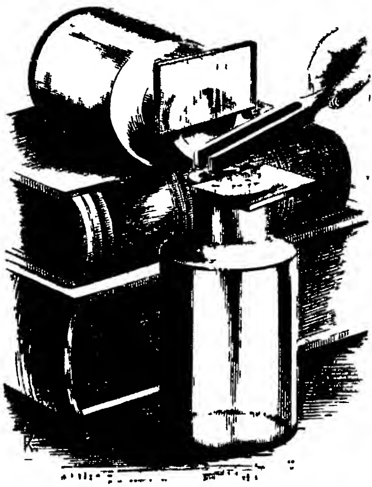


FIG. 40

is observed when the fork is in such a position that the condensation or rarefaction which comes out of one bottle exactly equals in power the rarefaction or condensation which comes out of the other.

You know that the air is really resounding in the bottles, even when silence is outside of them, by the following simple experiments :

• EXPERIMENT 65.—Slip a piece of cardboard over the mouth of one of the bottles, and at once the other bottle resounds to the fork and sings out loudly. The balance is thus broken and sound is heard.

EXPERIMENT 66.—A piece of tissue paper will produce another effect, because it is thin and only partly cuts off the vibrations, and the result is a feeble sound; partly an interference and partly a free action of the condensations and rarefactions, half silence, half sound.

EXPERIMENT SHOWING REFLECTION OF SOUND FROM A FLAT GAS-FLAME.

EXPERIMENT 67.—By a little care you can even slide the flat flame of a fish-tail gas-jet before the mouth of the horizontal bottle, and thus make a flame act as a guard to stop the vibrations from entering the bottle.

When two sonorous vibrations meet and make silence, they are said to "interfere." The experiments just made are experiments in the interference of sound.

EXPERIMENTS IN WHICH, BY THE AID OF A PAPER CONE AND A RUBBER TUBE, WE FIND OUT THE MANNER IN WHICH A DISK VIBRATES.

In describing Experiments 27, 28, 29, and 30, we stated that a vibrating disk always divided itself into an even number of sectors. This fact was explained by the statement that the adjoining vibrating sectors of the disk were always moving in opposite directions. The truth of this statement will be manifest on making the following experiments, which can only be explained by the fact that adjoining

sectors, at the same instant, are always in opposite phases of vibration. These experiments will also afford beautiful illustrations of the interference of sonorous vibrations.

Take a piece of cardboard and roll it into a cone about 10 inches long. The small end of the cone should have in it an opening of such a size that the cone will fit into the rubber tube used in Experiment 32. If a brass disk of 6 inches in diameter is used in the experiments, the mouth of the cone should be 2½ inches in diameter.

EXPERIMENT 68.—Make the plate vibrate with four sectors as in *A*, Fig. 23. Close one ear with soft wax; into the other put the end of the rubber tube; then place the centre of the mouth of the cone exactly over the centre of the plate with the cone quite close to its surface. In this position (which we will call No. 1, for future reference) no sound is perceived, or at least only a very faint one. This is so, because in this position of the cone it always receives four equal sound-pulses at the same instant from the vibrating disk; and as two of these are condensations, and two are rarefactions, they mutually neutralize each other, the drum-skin of the ear remains at rest and no sound is perceived.

EXPERIMENT 69.—Now move the mouth of the cone along the middle of a vibrating sector toward the edge of the disk. As the cone progresses the sound grows louder till it reaches its maximum when the edge of the cone reaches the edge of the disk. In this position (No. 2) the cone receives from the disk only regular sonorous vibrations, one condensation or one rarefaction alone entering the disk at a time.

EXPERIMENT 70.—Slowly move the cone along the circumference of the vibrating disk, keeping the edge of its mouth close to the border of the disk. The sound at once begins to diminish in intensity, until the circle of the mouth of the cone in its

progress is divided into two semicircles by a nodal line. No sound is now perceived, because in this position (No. 3) a condensation and a rarefaction enter the ear together, for on the opposite sides of a nodal line the plate has always opposite directions of motion.

EXPERIMENTS WITH BEATING SOUNDS.

EXPERIMENT 71 —In purchasing the two A-forks, you took special pains to get two which were tuned accurately to unison; otherwise they are of no value for our experiments. Take one of these in each hand and make them sound together. Hold them near each other close to the ear, and you will observe that while both sound there appears to be but one note. The two sounds blend together perfectly, so that we cannot distinguish one from the other. Having tried this thoroughly, place a bit of wax on the end of one of the forks, and then make them sound while each is held upright on its resonance box (*see* Experiment 41). At once you hear something unusual: little bursts of sounds, followed by sudden weakenings and loss of power, as if the forks sang *forte* and then *piano* alternately. These singular quivering changes in the tone of the two forks, when sounded together, are called "*beats.*" The sound seems to beat with a pulse-like motion at regular intervals. Take off the wax and the beats disappear, and the two forks sound together like one instrument.

EXPERIMENT 72.—Put on a larger or smaller piece of wax and the beats change their character, coming faster or slower each time the amount of wax is changed.

These experiments succeed admirably by using the tumblers of Experiment 43, or the resonant bottles of Experiments 63, 64, in place of the resonant

boxes. The tumblers or bottles should be carefully tuned, one to the loaded, the other to the unloaded fork.

To understand these singular beats, you must remember that each fork sends out sonorous waves, or alternate condensations and rarefactions, through the air. When the forks are sounded together (without the wax), each sends out the same number of waves in a second, and these travel out together, the condensations and rarefactions of each moving side by side, and reaching the ear at the same time.

When we loaded one fork with wax we caused it to move slower. The processions of waves streaming out from each may start together, but they do not keep together; as the loaded fork is going slower its waves of sound are longer and drag behind. The condensations and rarefactions no longer travel side by side. A condensation from one fork arrives at the ear at the same time that a rarefaction arrives from the other. Thus they interfere and destroy each other, and the interference makes silence, just as we discovered in our last experiments. The condensations and rarefactions from the two forks continue to arrive at the ear, and soon two condensations or two rarefactions come side by side and arrive at the ear together, and they mutually aid or reinforce each other, and there is a sudden burst of sound as if the forks were sounding louder.

The waves of sound continue to move, and one set of waves slips past the other, till the condensations of one set arrive at the ear alongside of the rarefactions of the other, and again there is interference and silence. By such continuous actions beats of sound are produced.

Fig. 41 represents two such series of waves travelling side by side. One series is represented by a full line, the other by a dotted one. At *A* the condensations of one series are shown as opposite the rarefactions of the other; but, as the waves

represented by the full line are longer than those represented by the dotted line, the former pass the latter, so that at *C* the two series act together, and we have a beat; while at a more distant point, *B*, the motions in the waves are opposed, and here there is interference and silence. It is evident that the sliding of the longer waves past the shorter will cause the waves, meeting at *B*, alternately to act together and to interfere; and thus the ear placed at *B*, will perceive beats of sound.

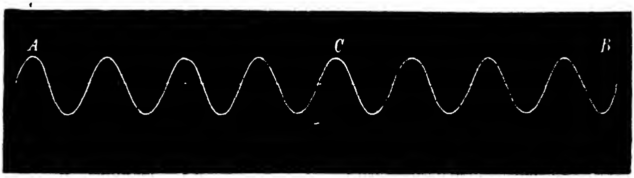


FIG. 41.

It necessarily follows that, if one fork vibrates 100 times in a second, and the other 101 times, there will be one beat in every second. The number of beats made in a second is equal to the difference in the number of vibrations per second made by the two vibrating bodies.

CHAPTER IX.

ON THE REFLECTION OF SOUND.

PROFESSOR ROOD'S EXPERIMENT, SHOWING THE REFLECTION OF SOUND.

EXPERIMENT 73.—Fig. 42 represents a disk of card-board 12 or 14 inches in diameter, and having two sectors cut out of it, on opposite sides of its centre. This is mounted on the rotator, so that it can be turned round quickly. Let some one sit beside the rotator so that he can turn the handle, and at the same time blow a toy trumpet, which I have found to be the best pipe for this experiment. Hold the trumpet so that it will be inclined to the surface of the disk, and with its open end just in front of one of the openings, as shown in Fig. 42. While the rotating disk is being turned steadily round, and the pipe is sounding, go to a distant part of the room, and here you will perceive the sound of the pipe changing rapidly, alternately growing louder and then softer like beats.

This effect is the result of reflection. When the solid part of the disk passes before the pipe the vibrations of sound are reflected or echoed from the card. When the openings pass before the pipe, part of the vibrations pass through the open place and are lost, and the sound appears to the listener to lose power.

In performing this experiment care must be taken to place the disk in such a position that the sound will be reflected to the distant listener. As we learned

in our experiments in *Light*, there is a law governing reflections. We found by our experiments that the angle of reflection is always equal to the angle of incidence, and the same law holds good in the reflection of sound.

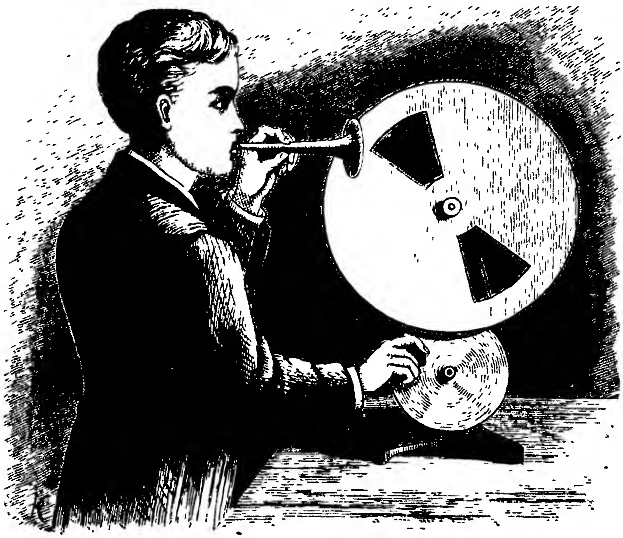


FIG. 42.

EXPERIMENT 74.—Another experiment in the reflection of sound may be made with a common palm-leaf fan. Let some one sound the trumpet at one end of a room, while you hold the fan upright beside one ear. While the trumpet is sounding, twirl the fan slowly by the handle, and you will observe a change in the sound. In certain positions of the fan the trumpet will sound louder, and in other positions it will be softened. If you do not obtain

this effect at once, try the fan in several positions as it stands upright, and, after a few trials, you will obtain a reflection of the sound from the surface of the fan. The sound of a locust on a warm day, or the beating of the surf on the shore, or the sound of a distant voice, may thus be caught on the fan and reflected into the ear.

Echoes are also reflections. The vibrations travel through the air and meet a building, then the side of a mountain or hill, and rebound or reëcho, perhaps many times.

EXPERIMENT 75.—You can readily find an echo anywhere in the country by walking near a barn or house and shouting or singing. The first trial may not bring out the echo, but, by changing your position, going nearer or walking farther away, and always standing squarely in front of the barn or other building, you will soon find the spot where an echo is heard. We already know that in winter, when the thermometer is at 32° Fahr., sound moves at the rate of 1,090 feet in a second. If you stand at 545 feet from the reflecting wall, and make a short, sharp sound, it will take one half second for it to go to the wall, and one half second to come back, and there will be one second between the sound and its echo.

In our experiments with the tuning-fork and two bottles that (*see* Fig. 40), you remember we put a piece of cardboard and a flat gas-flame before the mouth of one of the bottles. Here, also, we had a reflection of the sound from the cardboard, and even from the flame.

CHAPTER X.

ON THE PITCH OF SOUNDS.

EXPERIMENT 76.—Take one of the A-forks and the C-fork and stick them in the block of wood, side by side, with the opposite prongs of the two forks inclined to each other, so that by drawing a rod between them they will be set vibrating at the same time. Stick a piece of copper-foil on the tips of the prongs nearest each other, and arrange the smoked glass and its guide as directed in Experiment 25. Vibrate the forks by drawing the rod between them, and obtain the traces of their vibrations on the smoked glass.

Take the smoked glass and carefully measure off an equal space on each trace, and then count the vibrations inclosed in this space. If the right forks have been selected it will be found that $17\frac{1}{2}$ vibrations of one fork cover as much space as 21 vibrations of the other. From this we readily see that, in the same time, one fork vibrates oftener than the other. Carefully notice which fork makes the greater number of vibrations. Bring one vibrating fork to the ear, and then the other, and you will observe that the C-fork gives a higher note than the A. The C-fork makes the greater number of vibrations (21) in a given length on the trace, and the A-fork makes the smaller number ($17\frac{1}{2}$) in the same length. We are convinced by this experiment that a fork giving a high note vibrates oftener in a second than a fork giving a lower note. Experiments on all kinds of vibrating bodies—solids, liquids, and gases,—have proved that the pitch of a sounding body rises with the increase in the

number of its vibrations in a second. This fact may be stated thus: The pitch rises with the *frequency* of the vibrations. From the above fact it follows that the pitch of a sound rises with an increase in the number of sonorous waves that reach the ear in a second.

EXPERIMENTS WITH THE SIREN.

Fig. 43 shows an instrument called a siren. I will show you how to make several instructive and curious experiments with it. First, you will find out the number of vibrations made in a second by a sounding body like one of your tuning-forks: and, having found out this, you will use the fork to determine for yourself the velocity of sound. The siren will also tell you this important fact: That the numbers of vibrations per second which give the various notes of the gamut, or musical scale, bear to each other fixed numerical relations.

To make the siren, get a piece of cardboard, or millboard, and draw on it with a pair of dividers a circle $8\frac{1}{2}$ inches (21·6 centimetres) in diameter; then cut this circle out of the cardboard. Now draw four circles, the inner one with the legs of the dividers opened to $2\frac{1}{4}$ inches (5·73 centimetres), the next with a radius of $2\frac{3}{4}$ inches (6·99 centimetres), the third with $3\frac{1}{4}$ inches (8·26 centimetres), and the fourth with $3\frac{3}{4}$ inches (9·53 centimetres). Divide the circumference of the outer circle into 24 equal parts, and to each of these points of division draw a line from the centre, as shown in Fig. 44. Divide the spaces on the outer circle in halves; this will give 48 points on this circle. At each of these points cut a hole of about $\frac{3}{16}$ inch (5 millimetres) in diameter with a punch. Then punch holes at the 24 points on the inner circle.

The student, on looking at Fig. 4, will see that, on the radii marked 1, 2, 3, 4, 5, and 6, the holes are all

run in a line. These holes, thus in line, divide the circle into six equal parts. Divide each of these sixths on the second circle into five equal parts, and each sixth on the third circle into six equal parts and

FIG 43.

through each of these points of division cut a hole with the punch. By following these directions you will have made on the inner circle 24 holes, on the second 30, on the third 36, and on the fourth 48 holes.

Now cut a hole in the centre of the disk, so that it neatly fits on the screw of the small pulley of the rotator shown in Fig 43 Then put into a piece of India-rubber tube a glass tube having its interior about the diameter of the holes in the card disk We are now ready for our experiments.

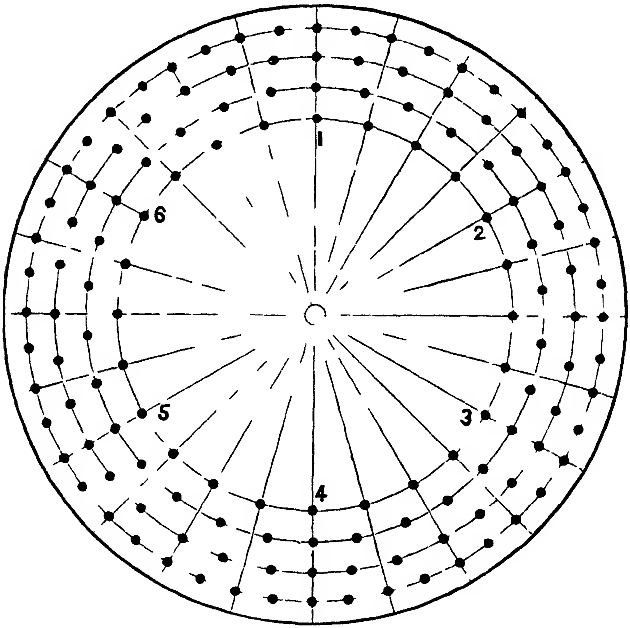


Fig 44

Experiment 77—Rotate the disk slowly, and, placing the glass tube before a ring of holes, blow through the tube. You will observe that whenever a hole comes before the tube a puff of air goes through the disk If the disk is revolved faster the puffs become more frequent, and soon, on increasing the velocity of the disk, they blend into a sound. Not very

pure, it is true; but, in the midst of the whizzing, your ear will detect a smooth note. Fixing your attention on this note, while the rotator is urged with gradually increasing velocity you will hear the note gradually rising in pitch. This again shows us that the pitch of a sound rises with the frequency of the vibrations causing it.

Two bodies make the same number of vibrations in a second when they give forth sounds of the same pitch. Therefore, if we can measure how many vibrations the disk makes in a second while it gives the exact sound of one of the forks, we will have measured the number of vibrations which the fork makes in a second. If we count with our watch the number of turns the crank *C* makes in one minute, we can from this knowledge calculate the number of puffs or vibrations the disk makes in one second, as follows: One revolution of the crank of the rotator makes the disk go round exactly five times. Now, suppose that the tube is before the third circle, having 36 holes, and that in one minute the crank *C* turns round 100 times. Then in one minute the disk turned 5 times 100 times, which is 500 times. But for each turn of the disk 36 puffs or vibrations were made on the air; therefore, 36 times 500, or 18,000, puffs or vibrations were made by the disk in one minute, and $\frac{1}{60}$ of 18,000, or 300, in one second.

But it is difficult to know just when the disk gives the same sound as the fork, and it is yet more difficult to keep the disk moving so that it holds this sound, even for a few seconds. To do this, very expensive apparatus has heretofore always been needed. But I did not wish to banish from our book such an important experiment, so I found out a cheap and simple way of doing it, which I will show you.

EXPERIMENT WITH THE SIREN, IN WHICH IS FOUND THE NUMBER OF VIBRATIONS MADE BY A TUNING-FORK IN ONE SECOND.

EXPERIMENT 78.—Get a glass tube (the same we used in the experiment on page 50 of *Light*) $\frac{3}{4}$ inch (19 millimetres) in diameter and 12 inches (30·5 centimetres) long, and a cork 1 inch thick, which slides neatly in the tube. Put the cork into one end of the tube, and holding a stick upright press the cork down on it. The fork is now vibrated and held over the open end of the tube, while the cork is forced up the tube with the stick till the column of air in the tube is brought into tune with the fork. This you will know by the tube sending out a loud sound. Try this several times till you are sure of the exact place where the cork should be to make the tube give the loudest sound.

Now lay the fork aside, and with small pieces of wax stick the tube on the top of a block, or on a pile of books, with its mouth close to the disk and facing one of the circles of holes, as shown in Fig. 43. On the other side of the disk, and just opposite the mouth of the resonant tube, hold the small tube through which you blow the air.

Turn the crank at first slowly, then gradually faster and faster. Soon a sound comes from the tube. This gets louder and louder; then, after the disk has gained a certain speed, the sound grows fainter and fainter, till no sound at all comes from the tube.

When the sound from the tube was the loudest, the disk was sending into the tube the same number of vibrations in a second as the fork makes; for the tube was tuned to the fork, and can only resound loudly when it receives from the disk of the siren the same number of vibrations in a second as the fork gives.

It is, then, quite clear that, to find out the number

of vibrations per second given by the fork, we first have to bring the disk to the velocity that makes the tube sound the loudest, and then to use this sound as a guide to the hand in turning the crank of the rotator. Practice will soon teach the hand to obey the check given by the ear; and if the student have patience, he will be rewarded when he finds that he can keep the tube sounding out loudly and evenly for 20 or 30 seconds. Then we count the number of turns made by the crank-handle *C* of the rotator in 20 or 30 seconds of the watch. If we have succeeded in this, we can at once calculate the number of vibrations the fork makes in one second.

The following will show how this calculation is made:

EXPERIMENT 79.—The cork was pushed to that place which made the air in the tube resound the loudest to the A-fork. The tube was then placed facing the circle of 36 holes. After we had succeeded in making the tube resound loudly and evenly to the turning disk, I counted the number of turns I gave to the handle *C* in 20 seconds, and I found this number to be 49. For one revolution of the handle *C*, the disk makes exactly five. Hence 5 times 49, or 245, is the number of turns the disk made in 20 seconds. But in one turn of the disk 36 puffs or vibrations entered the tube; therefore, 245 times 36, or 8,820, is the number of vibrations that went into the tube in 20 seconds; and $\frac{1}{20}$ of 8,820, or 441, is the number of vibrations which entered the tube in one second.

The experiment, therefore, shows that the tube resounds the loudest when 441 vibrations enter it in one second. But the tube also resounded its loudest when the vibrating A-fork was placed over it. Hence the A-fork makes 441 vibrations in one second.

EXPERIMENT 80.—Let the student now try to find out by a like experiment the number of vibrations made by the C-fork in one second. Repeat these

trials many times till numbers are found which do not differ much from one another.

FINDING THE VELOCITY OF SOUND BY AN EXPERIMENT WITH THE TUNING-FORK AND THE RESONANT TUBE.

EXPERIMENT 81.—Our experiment (78) with the glass tube has taught us that the tube must have a certain depth of air in it to resound loudly to the A-fork. Let us measure this depth. We find it to be $7\frac{2}{3}$ inches. (19·47 centimetres) when the air has a temperature of 68° Fahr.

From this measure, and from the knowledge that the A-fork makes 441 vibrations in one second, we can compute the velocity of sound in air.

It is evident that the prong of the fork over the mouth of the tube, and the air at the mouth of the tube, must swing to and fro together, otherwise there will be a struggle and interference between these vibrations, and then the air in the tube cannot possibly co-vibrate and strengthen the sound given by the fork.

We have already learned that the prong of the fork in going from *a* to *b*, Fig. 45, makes one half wave-length in the air before it. This may be represented by the curve *b c d* above the line *b d*. Now the tube *T* must be as long as from *b* to *c*, or *one quarter of a wave-length*; so that, by the time the prong of the fork has gone from *a* to *b*, and is just beginning its back-swing from *b* to *a*, the half-wave *b c d* has just had time to go to the bottom of the tube *T*, to be reflected back, and to reach the prong *b* at the very moment it begins its back-swing. If it does this, then the end of this reflected wave (shown by the dotted curve in the tube *T*) moves backward with the back-swing of the prong *b*, and thus the air at the mouth of the tube and the prong of the fork

swing together, and the sound given by the fork is greatly strengthened.

If the depth of the quarter of the wave made by the A-fork is $7\frac{2}{3}$ inches (19·47 centimetres), the whole wave is 30·64 inches, or 2·55 feet (77·88 centimetres). But we have already learned that, when the A-fork has vibrated for one second, it has spread 441 sonorous waves all around it. As one wave extends 2·55 feet (77·88 centimetres) from the fork, 441 waves will extend 441 times 2·55 feet (77·88 centimetres) or 1,124 feet (342·6 metres). This is the distance the

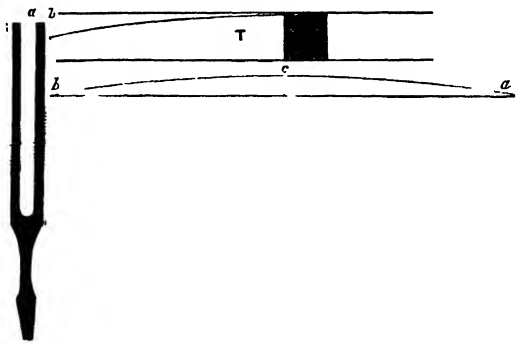


FIG. 45.

vibrations from the A-fork have gone in one second. In other words, this is the velocity of sound in air at 68° Fahr., as found out by the fork and resonant tube.

Thus we find that the most modest apparatus, when used with patience and thoughtfulness, can solve problems which, at first sight, may appear far beyond our power. The cardboard siren, the little tuning-fork, and the glass tube have measured the number of vibrations of the fork and the velocity of sound.

EXPERIMENT 82.—In a similar manner let the

student determine the number of vibrations of the C-fork, and then with it and the resonant tube let him measure the velocity of sound, and compare this result with that found with the A-fork.

THE NUMBER OF VIBRATIONS PER SECOND, GIVEN BY RESONANT TUBES AND ORGAN-PIPES, IS INVERSELY AS THEIR LENGTHS.

If the number of vibrations per second of the fork be doubled, the sonorous waves which it makes will be shortened one-half; hence the resonant tube must be shortened one-half in order to resound to the fork. If the vibrations of the fork are only half as frequent, it will make sonorous waves twice as long; hence to resound to this fork the tube must be doubled in length. These facts are stated in the following law: The lengths of resonant tubes are inversely as the numbers of the vibrations to which they resound.

But organ-pipes are merely resonant tubes whose columns of air, instead of being vibrated by a tuning-fork, are vibrated by wind passing through a mouthpiece; hence the following law: The lengths of organ-pipes are inversely as the numbers of vibrations which they give in a second.

CHAPTER XI.

ON THE FORMATION OF THE GAMUT.

EXPERIMENTS WITH THE SIREN, SHOWING HOW THE SOUNDS OF THE GAMUT ARE OBTAINED.

THE disk of our siren has four circles of holes. The innermost or first circle contains 24 holes, the second 30, the third 36, and the fourth or outermost circle has 48 holes.

EXPERIMENT 83.—Turn the handle of the rotator evenly and steadily, and at a moderate speed, and, while blowing through the tube, move it quickly from the inner ring of holes to the next, then to the next, and finally to the outer ring of holes. No experiment yet made brings so pleasant a surprise as this one. We have already found that the pitch of sound rises with the increase in the frequency of the vibrations causing it. As the tube moves from the first to the fourth circle, more holes successively pass before it in one turn of the disk; therefore the pitch rises suddenly as the tube reaches each circle in order. But, more than this, the successive sounds evidently have a familiar musical relation to each other, and this musical relation is not changed by turning the disk more or less rapidly. The pitch of the notes is thereby changed, but the same musical relation exists no matter how swiftly the disk turns during the experiment.

EXPERIMENT 84—A few trials will convince you that, when you sing the notes DO, MI, SOL, DO, you produce sounds which follow each other with

precisely the same musical intervals as when you blow air in order through the 24, 30, 36, and 40 holes in the disk. You have reached a grand truth lying at the very foundation of music. Your experiment tells you that, if four sounds are made by vibrations whose numbers per second are as 24 : 30 : 36 : 48, then these sounds will be those of four notes which bear to each other the same musical relation as exists among the notes DO, MI, SOL, DO. In other words, these four sounds will be the four sounds of what musicians call the perfect major chord.

Examining the numbers 24, 30, 36, and 48, we see that each of them may be divided by 6. Doing this, we obtain the four numbers 4, 5, 6, and 8. The ratios 4 : 5 : 6 : 8 are the same as held among the other numbers, but are simpler and easier to remember. Thus the perfect major chord will always be produced, if the ratios of the vibrations per second of four sounds are as 4 : 5 : 6 : 8.

EXPERIMENT 85.—By blowing first into the circle of 24 holes and then into the circle of 48 we hear two notes. The second is the octave of the first, and the fact is universally true that the octave of any sound is obtained by doubling the number of its vibrations.

With our siren we have just found out the relations of the numbers of vibrations per second which make the four sounds of the perfect major chord. But this simple instrument has even greater capacity than this. It can give us the related numbers of vibrations which form all the sounds of the gamut.

From the proportion 4 : 5 : 6 are derived all the sounds of the musical scale. These numbers form the very foundations of harmony. They should be engraved on the pediment of the temple of music.

It has been discovered by experiment that the numbers of vibrations giving the notes of the gamut, or, more properly, the sounds of the *natural* scale

of music, are related as is shown in the following proportions:

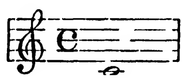
(1) 4 : 5 : 6 : : C : E : G.

(2) 4 : 5 : 6 : : G : B : d.

(3) 6 : 5 : 4 : : c : A : F.

Small c and d stand for the notes of the octave above C and D.

To form the gamut from these proportions, we must decide on the number of vibrations per second which shall give the sound C or DO. Let 264 vibrations per second be fixed as giving the C or DO of the octave below the treble, or



Then Proportion (1) becomes

C : E : G : : 4 : 5 : 6 : : 264 : 330 : 396.

Proportion (2) becomes

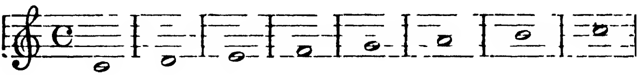
G : B : d : : 4 : 5 : 6 : : 396 : 495 : 594.

Proportion (3) becomes

c : A : F : : 6 : 5 : 4 : : 528 : 440 : 352.

Thus, by starting the first number of Proportion (1) with C, equal to 264 vibrations, we find that G will be given by 396 vibrations. Then starting Proportion (2) with G, equal to 396 vibrations, we find that B and the octave above D will be given by 495 and 594 vibrations. Therefore D is equal to one-half of 594, or 297. We start Proportion (3) with c, of 528 vibrations, the octave above C, and we obtain the numbers of vibrations per second which give the sounds A and F.

We write here in their proper order these notes of the gamut, and place under them their numbers of vibrations. The notes of the gamut are also designated as 1st, 2d, 3d, 4th, &c., so as to indicate what are called *intervals*. Thus the G forms to the C the interval of the 5th. The E is the interval of the 3rd to C.



C	D	E	F	G	A	B	c
264	297	330	352	396	440	495	528
1st	2nd	3rd	4th	5th	6th	7th	8th.

An examination of these numbers will show that each may be divided by eleven. Doing this, we obtain the following series of numbers, which give the *relative* numbers of the vibrations for the notes of the gamut in any octave of the musical scale:

$$C : D : E : F : G : A : B : c.$$
$$24 : 27 : 30 : 32 : 36 : 40 : 45 : 48.$$

EXPERIMENT 86.—Of the correctness of the above mode of forming the gamut, you may convince yourself by cutting another disk for the siren having eight instead of four circles of holes, each circle having, in order, these numbers of holes, viz.; 24, 27, 30, 32, 36, 40, 45, 48. Turning the disk, by giving to the crank a uniform motion of 22 revolutions in 10 seconds, while you successively blow into the circles, you will hear in succession the eight notes of the gamut of the octave of C, of 264 vibrations.

EXPERIMENT 87.—Even the disk with four circles of holes may be made to give all the notes of the gamut, but only four notes in each experiment.

You will find on making the calculation that, if you turn the handle of the rotator 22 times in 10 seconds, you will make the C of Proportion (1);

33 turns in 10 seconds, will give the G of Proportion (2); while $29\frac{1}{3}$ turns in 10 seconds will give the F of Proportion (3). Hence, if you blow into the four circles of holes, while the disk has in succession these three different velocities, you will successively get the numbers of vibrations making the sounds of the gamut given in Proportions (1), (2), and (3).

CHAPTER XII.

EXPERIMENTS WITH THE SONOMETER, GIVING THE SOUNDS OF THE GAMUT AND THE HARMONICS.

FIG. 46 represents a wooden box 59 inches (150 centimetres) long, 4¾ inches (12 centimetres) wide, and 4¾ inches (12 centimetres) deep. The sides are made of oak ½ inch (12 millimetres) thick, and the

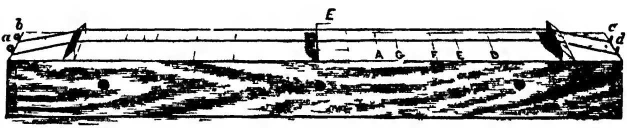


FIG. 46.—THE SONOMETER.

two ends of oak 1 inch (25 millimetres) thick. These are carefully dove-tailed together. In the side-pieces are cut three holes, as shown in the figure. There is no bottom to the box, and the top is made of a single piece of clear pine ⅛ inch (3 millimetres) thick, and glued on. Two triangular pieces, ⅞ inch (2 centimetres) high, and glued down to the cover of the box, just 47¼ inches (120 centimetres) apart, form bridges over which the wires are stretched. There is also, as shown at *E*, a loose piece of pine 2½ inches (6.35 centimetres) wide, ⅞ inch (2 centimetres) thick, and about 4¾ inches (12 centimetres) long. At *a*, *b* are two screw-eyes set firmly upright at one end of the box in the oak. At *c*, *d* are two piano-string pegs. From these to the screw-eyes are stretched

two pieces of pianoforte wire (No. 14, Poehlemann's patent, Nuremberg). In putting on these wires, the ends must be annealed, by making them red-hot in a stove, before they are wound round the screw-eyes or pegs. Such an instrument is called a sonometer, and will make a useful and entertaining instrument for our experiments. When it is finished, the wires may be drawn up tight by means of a wrench or piano-tuner's key, and then we shall find, on pulling the wire one side and letting it go, that it gives a clear tone that lasts some time.

EXPERIMENTS WITH THE SONOMETER, GIVING THE SOUNDS OF THE GAMUT.

EXPERIMENT 88.—Place the sonometer (Fig. 46) in front of you, and with a metric measure lay off distances from the left-hand bridge to the right, of 60 and 30 centimetres. Tighten the wire till it gives, when plucked, a clear musical sound, not too high in pitch. Then place the block *E* (Fig. 46) under the wire, with its edge on the line marked 60 centimetres, and place the end of the finger on the wire at this edge of the block. Pluck the wire at the middle of this length of 60 centimetres, and listen attentively to the pitch of the sound. Then at once remove the block and pluck the wire in its middle so that the whole wire vibrates. You will perceive that the sound now given is like the one given when the half-wire vibrated, only it differs in this, that it is the octave below it. With the block placed at 30 centimetres, vibrate one-quarter of the length of the wire, and you will find that we have the sound of the first octave above that made by half the wire, and the second octave above the sound given by the whole wire.

Our siren has proved that by doubling the number of vibrations the sound rises an octave. Therefore,

when a wire is shortened one-half it vibrates twice as often, and when shortened one-quarter it vibrates four times as often, as when its whole length vibrates. This then is the rule, or law which governs the vibrating wire. The force stretching the wire remaining the same, the vibrations of the wire become more frequent in direct proportion as its length is shortened. Thus, if the wire be shortened $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{3}$, or $\frac{1}{9}$, the number of its vibrations per second will increase 2, 4, 3, or 9 times.

EXPERIMENT 89.—Knowing this law we can readily stretch a wire on the sonometer till it gives say the C of 264 vibrations per second, and can then determine the various lengths of this wire which when vibrated will give all the notes of the gamut. We have seen that the relative numbers of vibrations which give the sounds of the gamut are as follows:

Notes	C	D	E	F	G	A	B	c
Relative number of vibrations ..	24	27	30	32	36	40	45	48
Lengths of wire (in centimetres).	120	$106\frac{2}{3}$	96	90	80	72	64	60

We have seen that, if the whole length of 120 centimetres of wire gives C, then 60 centimetres must give c of the octave above, and, as the relative numbers of vibrations of G and C are to each other as 36 is to 24, it follows that the length of the C-wire must be longer than the G-wire in the ratio of 36 to 24. Hence the proportion 36 : 24 : : 120 : 80 gives 80 centimetres as the length of the G-wire. In like manner the lengths of wire which give the other sounds of the gamut have been calculated. In the third line of the above table we have given these lengths in centimetres. Lay off these lengths on the sonometer, always measuring from the left-hand bridge toward the right, and draw lines across the top of the sonometer through these points of division

and letter them in order D, E, F, G, A, B, c. If you now place the block *E* (Fig. 46) successively at these divisions, and vibrate the fractions of the wire so made, you will obtain in succession the notes of the gamut.

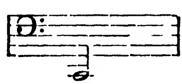
EXPERIMENTS WITH THE SONOMETER, GIVING THE HARMONIC SOUNDS.

There is another series of sounds called ***the harmonic sounds***, in which the relative numbers of the vibrations making them are as 1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 9 : 10, &c. The law ruling the vibrations of wires and strings teaches us that this series of sounds will be given by the sonometer if we vibrate its wire after it has been successively shortened $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$, $\frac{1}{8}$, $\frac{1}{9}$, $\frac{1}{10}$, &c., of its whole length.

EXPERIMENT 90.—Again place the sonometer before you, and taking the metric measure divide the length of the top between the bridges into $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$, $\frac{1}{8}$, $\frac{1}{9}$, $\frac{1}{10}$ of 120 centimetres. This is done by measuring in order from the left-hand bridge (Fig. 46) toward the right, 60, 40, 30, 24, 20, 17.14, 15, 13.33, and 12 centimetres. Draw lines through these points of division across the top of the sonometer, and number them in order $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$, $\frac{1}{8}$, $\frac{1}{9}$, $\frac{1}{10}$.

Now place the block *E* at each of these lines of division and vibrate the successive fractions of the wire, and you will have produced in order the sounds of the harmonic series.

If we make the whole string vibrate the sound of



66 vibrations per second, then the harmonic series of this C will be as follows. The numbers of vibrations

are written under the names of the notes. The latter are given in letters accented to indicate the octaves.

C	c	g	c'	e'	g'	b'♭	c''	d''	e'
66	132	198	264	330	396	462	528	594	660
1 :	2 :	3 :	4 :	5 :	6 :	7	8 :	9 :	10

The lowest sound of a harmonic series is called by the names of *fundamental*, or *first harmonic*, or *prime* The other sounds are known as the 2d, 3d, 4th, &c., harmonic, or as first upper partial tone, 2d upper partial tone, &c, or as 1st, 2d, 3d, &c, harmonic overtones.

The harmonics of the wire may be obtained in other ways, making the following series of beautiful experiments:

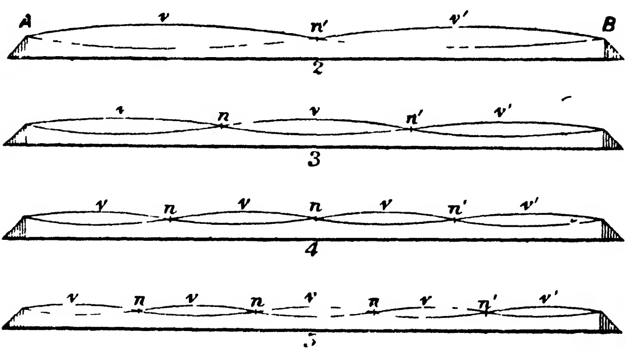


FIG 47.

(2), (3), (4), and (5), of Fig. 47, show a wire *A B*, which has been made to divide itself into 2, 3, 4, and 5 separate vibrating parts, lettered *v*. These vibrating parts, or *ventral segments*, as they are sometimes called, are separated from one another by points marked *n*, called *nodes*, where the wire is nearly at rest. Adjoining ventral segments are always vibrating in opposite directions; that is, while one is going up the other will be going down, making a sort of seesaw motion around the points *n*.

As $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{5}$, &c., of a wire vibrates 2, 3, 4, and 5 times as frequently in a second as the whole length of wire, it follows that (2), of Fig. 47, gives the 2d harmonic, (3) gives the 3d, (4) the 4th, and (5) the 5th harmonic.

EXPERIMENT 91.—With a violin-bow the wire may be divided into as many as ten vibrating ventral segments. Place the tip of the finger or the beard of a quill successively over the harmonic division lines on the sonometer, at *n'*, Fig. 47, and draw the bow across the string at *v'*, and the wire will divide itself into vibrating parts whose number will equal the number of the harmonic sound given by the wire.

If little paper riders of this form ⅄, be placed on the string at the points *n'*, *n*, *n*, *n*, &c., and *v'*, *v*, *v*, *v*, &c., on vibrating the wire the riders will remain seated at the points *n'*, *n*, &c., but those at the points *v'*, *v*, &c., will be thrown off.

Soon we shall find these harmonic sounds becoming very interesting to us, for they will serve to explain things about sounds which, until quite recently, had remained unknown.

PROFESSOR DOLBEAR'S METHOD OF MAKING MELDE'S EXPERIMENTS ON VIBRATING CORDS.

EXPERIMENT 92.—"To one prong of a small pocket tuning-fork tie a piece of silk thread, six or eight inches long, and to the other end tie a pin-hook, and hang upon it a small weight, say a shirt-button. Project this with a lens on a screen. First, with the fork held in a horizontal position, vibrate the prongs in a vertical plane. The string will divide up into segments, all of which can be plainly seen and counted. Second, turn the fork so that it vibrates in a horizontal plane. The number of segments will be doubled."

We have found it preferable to use balls of wax instead of buttons, so that the precise tension of string required in these experiments may be reached by altering the size of the suspended wax. It will be found that the number of segments into which the string divides is inversely as the square roots of the weights of the wax balls. This fact shows that the frequency of the vibrations of a string varies inversely as the square root of the stretching force applied to it.

CHAPTER XIII.

ON THE INTENSITIES OF SOUNDS.

EXPERIMENT SHOWING THAT, AS THE SWINGS OF A VIBRATING BODY BECOME LESS, THE SOUND BECOMES FEEBLER.

YOUR experiments have shown you that the pitch of a sound rises with the frequency of the vibrations. You no doubt have observed that sounds may be loud or soft without regard to their pitch. Thus, just after we have vibrated a tuning-fork, its sound is the loudest, then it gradually grows feebler and feebler, and slowly dies out.

EXPERIMENT 93.—Let us make an experiment which will tell us the cause of this gradual change in the intensity of its sound.

Vibrate the fork as shown in Experiment 25, and very slowly draw the smoked glass under the pointed piece of foil which is fastened to one of the prongs. As the glass slowly moves under the vibrating fork you will observe that the sound grows feebler and feebler, and at last it dies out.

Take the glass and examine the trace made by the vibrating fork. You see that the lamp-black has been scraped from the glass in a triangular-shaped space,

as shown in Fig. 48. This shows that, as the sound diminished in intensity, the extent of the swings of the fork grew less and less.

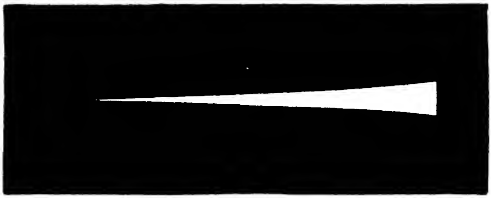


Fig. 48

CHAPTER XIV.

ON CO-VIBRATIONS.

EXPERIMENTS WITH TWO TUNING-FORKS.

EXPERIMENT 94.—Take the two tuning-forks that we used in the experiments in interference, holding one upright before you make the other vibrate, and then bring the two close together, with the surfaces of their prongs opposite each other. One is silent and motionless, the other is vibrating. Hold them there for a few seconds, and then bring the fork that was silent quickly to the ear, and you will discover something quite surprising. It is not silent, it is sounding faintly. It has not been touched, and yet it is vibrating. Why should a fork begin to vibrate merely because a sounding fork is near it?

EXPERIMENT 95.—Get the two wooden boxes or resonators we made for these forks (A-forks) and place them on a table with the open ends facing each other, and a few inches apart. Hold one of the forks upright on one of the boxes, and then, making the other fork sound, place it on the other box. It now sounds clear and loud. Stop this vibrating fork by touching it with the finger, and the other fork will be heard sounding alone. This is certainly a most curious matter. That one fork can cause another near it to sound, is something that seems nearly impossible, and yet our experiment shows that it is so.

EXPERIMENT ON THE CO-VIBRATION OF TWO WIRES ON THE SONOMETER.

EXPERIMENT 96.—Stretch the two wires on the sonometer (Fig. 46) so that they come in tune with each other. If you cannot do this, get some one familiar with music to help you, and let him bring the two strings into unison. When this is done, pull one of the strings at the centre and let it go and then watch the other string. At first it is at rest and silent, but in an instant it too begins to quiver and sound. You may repeat this several times, and each time you will observe the same thing. One string sounding near another causes it to sound also.

EXPERIMENT 97.—Loosen the second wire slightly and put it out of tune with the first, and the experiment fails completely. Take another fork, not in tune with the one that sounds, and Experiment 95 will also fail. Here we are coming on a fact in this matter that may help us out. When the two forks are alike, when the two strings of the sonometer are in tune, the sounding fork or string makes its neighbour sound with it.

This remarkable fact, that a vibrating body may cause another elastic body in tune with it also to vibrate, is called co-vibration; which means, vibrating with (another body).

The fork (or string, or any body), in vibrating, gives to the molecules of the surrounding air the same number of pushes and pulls in one second as the silent fork does when it vibrates.

Suppose that the silent fork receives a feeble push from the vibrating air which touches it. The prong of the fork is pressed forward, but through a very minute distance; then it swings back by its own elasticity, but it swings back with the air, which now pulls it. Then, on reaching the end of this backward swing it at once gets another push from the air, and this

push aids it on its forward swing, and makes it swing a very little more than it would have done if it had not received this push. Thus the little pushes and pulls of the air keep exact time with the tiny forward and backward swings of the fork, and, as several hundreds of these pushes and pulls act on the fork in a second, they soon get it swinging sufficiently to make it act with power enough on the air to give us a sound when the other fork is stopped.

An exact understanding of how these feeble pushes and pulls of the air can set into vibration such a stiff and heavy body as a steel fork may be assisted by the following:

EXPERIMENT OF SWINGING A HEAVY COAL-SCUTTLE BY THE FEEBLE PULLS OF A FINE CAMBRIC THREAD.

EXPERIMENT 98.—Take a very heavy body, like a scuttle full of coal, and suspend it by a stout piece of twine. Then tie a piece of the finest cambric thread to the handle on the back of the scuttle. When the scuttle is hanging motionless give the cambric thread a feeble pull, being careful not to pull too hard or you will break it. Now you will see, by looking sharply, that you have set the scuttle swinging, but through a very small distance. Again gently pull the thread when the scuttle is swinging toward you, and repeat this pull several times, always keeping time with the swing of the scuttle. Now the scuttle is swinging through an inch or two, and by keeping up the pulls you may be able to swing it through a foot or more. But if your pulls on the thread are not in time with the swings of the scuttle you will not be able to swing it.

EXPERIMENT 99.—Now that the scuttle is swinging through a foot or so, hold the thread fast so that it cannot follow the scuttle. It snaps asunder and

the scuttle goes on its way, as far as you can see, as though it had received no check at all on its speed. This is so because the strongest pull you can give through the thread to stop the scuttle is only a very small part of the force you have already given the scuttle by your many small pulls through the thread.

As the many feeble pulls of the delicate thread at length made the scuttle swing with great force, so the many feeble pushes and pulls of the delicate air brought the fork into a state of vibration powerful enough to make all the air in the room tremble.

This co-vibration may be found wherever two bodies in tune are placed near each other. Co-vibration explains why the tuning-forks sounded so much louder when placed on the resonant boxes. The volume of air inside the box is in tune with the fork, and it takes up the vibrations sent through the box, and, vibrating with the fork, the united vibrations make the sound so much the louder. The air in the tumbler and bottles of Experiments 43 and 63, and the air enclosed in glass tubes, as in Experiments 78 and 81, also move by co-vibration. It is also by the co-vibration of resonant pipes that the feeble notes on the lips and reeds of organ-pipes are made full and powerful.

CHAPTER XV.

ON CHANGES IN THE PITCH OF A VIBRATING BODY CAUSED BY ITS MOTION.

EXPERIMENT IN WHICH THE PITCH OF A WHISTLE IS CHANGED BY SWINGING IT ROUND IN A CIRCLE.

EXPERIMENT 100.—Take the piece of rubber tubing used in Experiment 32 and fit it over the mouth of the whistle used in Experiment 33. Let some one go to the end of the room or stand at a distance out-of-doors. Then, by the tube swing the whistle round in a vertical circle, and at the same time blow through the tube so that the whistle will sound. The observer will see the whistle alternately coming toward him and going away from him, and with these motions he will hear the pitch of the whistle rising and falling.

In this experiment the sounding body is moving, and its movements cause a change in the number of vibrations which the ear receives in a given time. When the whistle swings toward the observer the sonorous waves are crowded together, and they reach the ear in greater number than when the whistle is at rest, and the note appears to have a higher pitch. On the other hand, when the whistle moves away from the observer, its backward movement draws out the sonorous waves, and fewer vibrations are given to the ear than when the whistle is at rest. Thus we

see how the motion of a vibrating body changes the pitch of its sound.

EXPERIMENT 101.—You must notice the same thing on the railway, where the sound of the whistle or bell of a moving locomotive appears to change in pitch as the engine draws swiftly near and then passes quickly away from us.

CHAPTER XVI.

ON THE QUALITY OF SOUNDS.

WHEN you hear the sound of a violin, flute, clarinet, trumpet, piano, or organ, you readily recognize the sound of each instrument though it may not be in sight. Some one sings or speaks, and another person sings near him or after him, and we at once recognize each singer's or speaker's voice; and if we are familiar with his voice we can give his name, even if we do not happen to see him. This leads us to think that there must be some other characteristic of sounds besides pitch and intensity.

The flute, the violin, the clarinet, the singer, may each give the same note, and with equal power, yet the note of each has a character of its own, a peculiar something that distinguishes it from the same note given by the other instruments or singers. This we call *the quality* of the sound (sometimes called *timbre* or *character*). Let us now make some

EXPERIMENTS ON THE QUALITY OF SOUNDS.

The experiments now to be made are of a peculiarly fascinating character. They will have for their object the discovery of what gives to sounds their various qualities. These experiments will lead us to the understanding of some of the laws of music.

All sounds may be divided into two great divisions. They are either *simple sounds* or *compound sounds.*

EXPERIMENT 102.—A simple sound is one in

which the ear cannot distinguish two or more sounds differing in pitch. Hold one of your vibrating forks over the resonant tumbler, tuned by partly closing its mouth with the glass plate, as shown in Experiment 43. You are now listening to a simple sound, a sound in which the ear can detect only a sound of one pitch. A wide closed organ-pipe also gives a simple sound. All simple sounds have necessarily the same quality, for they differ only in pitch and intensity.

A compound sound is a sound formed of two or more simple sounds, all differing in pitch. Such is the sound given by a piano-wire. It may surprise you to learn that more than one sound is heard when you strike a piano-key which can vibrate only one wire. Yet this is so.

EXPERIMENT 103.—Strike the c″-key of the piano and sound your c″-fork. Though the same note in written music stands for each of these sounds, yet your ear at once perceives a marked difference in them. Now fix your attention on the sound given by the fork alone. Remembering well this sound, strike the c″ of the piano. You now recognize that the c″ of the fork is the sound of in the piano c″; but after some practice the ear begins to hear other sounds in the piano c″—sounds which are evidently *higher in pitch* than the pitch of the fork's c″.

The c″ of the fork is certainly the loudest simple sound heard in the piano c″, and it is also the gravest; therefore the compound sound given by the piano is given in written music by the same note which stands for the c″ of the fork.

But what are the higher sounds mingled with this c″? I will first answer this question in the most general manner, then you must make for yourself the experiments which will answer it better than my words.

All compound musical sounds are formed of simple sounds, and these simple sounds are the sounds of

the harmonic series. You have already become acquainted with these sounds. You know that the relative numbers of the vibrations giving them are as 1 : 2 : 3 : 4 : 5 : 6, etc. The gravest (1) of this series of sounds is called the fundamental. It is also nearly always the loudest, and the compound sound is named after it. This is the sound of the c″-fork heard in the c″ of the piano.

If what I have said is so, then if you strike the C below the middle C on the piano you will cause other sounds to come forth at the same time, sounds which are the harmonics of C, and are given by the following notes written in the treble stave, and numbered 2, 3, 4, 5, 6, 7, and 8. Experiment 104 of the next chapter shows that this is so.

CHAPTER XVII.

ON THE ANALYSIS AND SYNTHESIS OF SOUNDS.

AN EXPERIMENTAL ANALYSIS OF THE COMPOUND SOUNDS OF A PIANO.

EXPERIMENT 104.—Take your seat in front of the keys of the piano, and slowly and steadily press down the key of the note c′, marked 2 in the above notation. The damper will lift from off the wire, the hammer will ascend, touch the wire and then fall. Thus this wire is free to vibrate. Now strike strongly the fundamental note c, marked 1, and, holding it for a few seconds remove the finger. This wire ceases to vibrate, but at once there comes to the ear a higher note. It is the sound of the free wire of note 2. This experiment shows that the number of vibrations which make the sound of note 2, or c′, must have been in the sound of note c, or 1, otherwise the wire of c′ could not have entered into vibration. Evidently the wire c′ *co-vibrated* to the simple sound c′ contained in the compound sound of the fundamental note c, or 1.

Now make similar experiments by depressing in order the keys of the notes g′, c″, e″, g″, c‴, marked respectively 3, 4, 5, 6, and 8. You will discover that the wire of each of these notes will co-vibrate to the compound sound of c, showing that each of these sounds exists in the c of the piano.

Some of these notes will sound out louder or feebler than others, showing that they exist with more or less force in the compound sound. This fact proves that

the quality of a sound does not alone depend on the number of the simple harmonic sounds which compose it, but also on their relative intensities. It can indeed be shown by calculation that, if the compound sound be formed of six simple harmonic sounds, you can, by giving to each harmonic only two different degrees of intensity, form by their various combinations upward of 400 different qualities of sound; and with four different degrees of intensity allowed to each of the six harmonics their combination can produce over 8,000 different qualities of sound. Thus you see how varied may be the qualities of sounds even when they contain the same simple sounds.

But the same harmonics do not exist in all compound sounds. The flute-sounds may contain two or three harmonics. The clarinet-sounds are formed of the fundamental, the 3d, the 5th, and the 7th. The violin-sounds contain all the harmonics up to the 7th, and often to the 10th. The composition of piano-sounds varies with their pitch. The deeper tones are rich, but the higher are poor in harmonics. In the lower octaves the 3d harmonics are often as loud as the fundamental harmonic, and the 2d harmonic is often even louder. Reed organ-pipes are very rich in harmonics, often extending as high as the 20th, and readily detected by a practised ear, which can pick one after another out of the compound sound, almost to the exclusion of hearing of the rest. The human voice is rich in harmonics, and varies much in quality, as we all know from listening to different singers. The quality also varies with the pitch of the notes sung, as will be shown by experiments with Konig's vibrating flames. *(See* Experiment 112, and following).

EXPERIMENTS IN WHICH WE MAKE COMPOUND SOUNDS OF DIFFERENT QUALITIES BY COMBINING VARIOUS SIMPLE SOUNDS.

EXPERIMENT 105.—*The flute-sound* may be made by combining a simple sound with its octave. The following experiment produces it very well: You found that a column of air, in a tube, just one-fourth of the length of the sonorous wave given by a fork, will strengthen by its co-vibration the sound of the fork. If you make the column of air in the tube only one-eighth of the length of the wave it will resound to the octave of the fork, for columns of air in tubes (as shown on page 122) follow the same law of vibration as stretched wires and strings; that is, their vibrations increase in frequency directly as the air-column is shortened.

The depth of air-column which resounds to the A-fork is $7\frac{2}{3}$ inches (19·47 centimetres). Push the cork up the glass tube (*see* Experiment 78) till you have an air-column one-half of this length, or 3·83 inches (9·73 centimetres). Now vibrate the fork and bring it over the mouth of the tube. A clear flute-like sound comes forth. It is formed of the A-note of the fork mingled with its octave given by the resonant tube. By properly varying the distance of the fork from the tube, and both from the ear, you will after a few trials obtain a sound which you can barely distinguish from that of a flute.

EXPERIMENT 106.—*The sounds of the human voice* can be formed out of its simple sounds by using the co-vibration of the strings of the piano.

Lift the top of the piano. Strike a key and then sing it till you are sure that you have its pitch. Press down the pedal so that the dampers are lifted from all of the wires, then lean over the wires and clearly and steadily sing the note. Stop and listen. The piano answers back, and the sound of your voice is

heard as though coming from a distance. Each string which is in tune to a harmonic in your voice co-vibrates with that harmonic, and all of the harmonics of your voice are thus sounded by the strings of the piano. The combination of all these co-vibrations builds up the quality of your voice and echoes it back to you.

EXPERIMENT 107.—If you now sing again the same note, and press down one after the other the keys of its harmonics, as we did in our other experiment with the piano, you may find out what harmonics compose your voice, and get some idea of their relative strengths.

EXPERIMENT 108.—If a cornet, a clarinet, our little toy trumpet, or other instrument, be sounded over the freed strings of the piano, their sounds will be analyzed, by the co-vibrations of these strings Then the sounds of the strings melt into one compound sound, which is the reproduction of the sound of the instrument which set the strings in motion.

Thus we see that every musical sound, whether from voice or instrument, is formed of a fundamental combined with a certain number of harmonics.

Your unpractised ear may not always be able to pick them one by one out of the tangle of sound. Yet there they exist, giving those delicate and ethereal qualities which characterize the various sounds of Nature and of music.

HOW THE EAR ANALYZES A COMPOUND SOUND INTO ITS SIMPLE SOUNDS.

The experiments with the piano serve to explain the wonderful power of the ear in analyzing compound sounds In the cochlea (snail-shell, *C* of Fig. 4) of the ear are supposed to exist co-vibrating fibres which are tuned to simple sounds extending over several octaves. To each tuned fibre is fastened a fine

filament of the auditory nerve. A simple sound is only given by *a pendular vibration.* A compound sound is a sensation made by several pendular vibrations of various frequencies entering the ear together. If one pendular vibration enters the ear it vibrates the nerve-filament fastened to the fibre which is tuned to this pendular vibration, and we have the sensation of a simple sound.

But when a compound vibration, made up of several simple pendular vibrations, enters the ear, it acts on several tuned fibres, exactly as our voice, or the sounds of the cornet or trumpet, acted on several piano-strings. Each fibre in the ear enters into vibration with that pendular vibration in the compound sound with which it is in tune. Thus the nerve-filaments which are fastened to fibres in the ear tuned to the simple sounds in the compound sound are shaken, and the sensation of the latter is thus analyzed into its simple sound sensations. What we have just said at once suggests the question: What sort of motion has a molecule of air when it is acted on at the same time by several pendular vibrations? This is answered by

AN EXPERIMENT WHICH SHOWS THE MOTION OF A MOLECULE OF AIR, OR OF A POINT ON THE DRUM-SKIN OF THE EAR, WHEN THESE ARE ACTED ON BY THE COMBINED PENDULAR VIBRATIONS OF THE FIRST SIX HARMONICS.

We have seen, in Experiment 11, that the pendular motion may be obtained by sliding a card, with a slit in it, over the sinusoidal trace of a vibrating rod. Imagine a similar trace made by a point whose motion is formed of the combined vibratory motions of the first six harmonics. Such is the trace drawn on the line *c d* of Fig. 49.

EXPERIMENT 109.—If we slide, in the direction

c d, a card with a slit in it over this trace, you will see in the slit the same vibratory motion, only much slower, that a point of the drum-skin of the ear has when we hear a compound sound (like that of the piano-wire) which contains the first six harmonics. The student of course remembers that the direction of the length of the slit is in the direction in which the sonorous vibration is travelling through the air.

FIG. 45.

The curve on *c d* I obtained as follows: I drew on the line *a b* the six sinusoids, having their lengths as 1 : 2 : 3 : 4 : 5 : 6. Another line, *c d*, was drawn below and parallel to *a b*, and then 500 equidistant lines, perpendicular to *a b*, were drawn through the curves on *a b* and extended below the line *c d*. On each of these vertical lines I got the algebraic sum (calling the distances above *a b* + and those below *c d* –) of the distances of the curves above or below *c d*, and then transferred this sum to the corresponding vertical line passing through *c d*. Through the points thus found, above and below *c d*, I drew the curve which you see on *c d*.

EXPERIMENT 110.—This curious compound sonorous motion is best exhibited as follows: On a piece of cardboard draw a circle, and in one quadrant of this circle draw 500 equidistant radii. Make the length of these radii vary with the corresponding distances of the curve (Fig. 49) above and below the

FIG. 50.

line *c d*. Join the ends of these radii with a curve. By repeating this curve four times on the cardboard you will have made the curve continuous, as is shown in Fig. 50. Now cut this curved figure out of the cardboard, and thus form a templet. Place this, centred, on a glass disk of a foot in diameter, covered

with opaque black varnish. With the separated points of a pair of spring dividers go round the edge of the templet, and thus remove the varnish in a sinuous band, as shown in Fig. 50.

The glass disk is now mounted on the rotator, and placed between the heliostat and a plano-convex lens, as shown on page 79 in our book on "Light" of this series. A magnified image of that portion of the curve which is in front of the heliostat is thus obtained on a screen. A piece of cardboard, having a narrow slit cut in it, is now placed close to the disk and in the direction of its radius. Revolving the disk you will have on the screen a vibratory motion like that which a molecule of air, or a point on the drum-skin of the ear, has when these are acted on by the combined pendular vibrations of the first six harmonics of a musical note

On slowly rotating the disk one can readily follow the compound vibratory motion of the spot of light on the screen. On a rapid revolution of the disk the spot appears lengthened into a luminous band, but this band is not equally illuminated. It has six distinct bright spots in it, beautifully showing the six bends in the curve on the disk.

EXPERIMENT 111.—The student, however, need not go to the expense of buying the glass disk. He is able, no doubt, to copy on a cardboard the curve, about three times as large as Fig. 50, and then, turning it on the rotator before a slit in a card, he may study at his leisure this curious motion. He can even get this motion directly from the figure in his book by sticking a pin in the centre of Fig. 50, and about this revolving a card with a fine slit in it.

EXPERIMENTS BY WHICH COMPOUND SOUNDS ARE ANALYZED BY VIEWING IN A ROTATING MIRROR THE VIBRATIONS OF KONIG'S MANOMETRIC FLAMES.

Take a piece of pine board, *A*, Fig. 51, 1 inch (25 millimetres) thick, $1\frac{1}{2}$ inch (38 millimetres) wide, and 9 inches (22·8 centimetres) long. One inch from its top bore with an inch centre-bit a shallow hole $\frac{1}{8}$ inch deep. Bore a like shallow hole in the block *B*, which is $\frac{3}{4}$ inch thick, $1\frac{1}{2}$ inch wide, and 2 inches (51 millimetres) long. Place a $\frac{1}{2}$-inch centre-bit in the centre of the shallow hole in *A* and bore with it a hole through the wood. Into this fit a glass or metal tube, as shown at *E*. Bore a $\frac{3}{16}$ inch (5 millimetres) hole obliquely into the shallow hole in *B*, and into this fit the glass tube *C*. Then bore another $\frac{3}{16}$ inch hole directly into the shallow hole in *B*. Put a glass tube in a gas or spirit flame and heat it red-hot at a place about two inches from its end. Then draw the tube out at this place into a narrow neck. Make a cut with the edge of a file across this narrow neck, and the tube will readily snap asunder at this mark. Then heat a place on the tube in a flame, and here bend it into a right angle, as shown at *D*, Fig. 51. Now fit this tube into the hole just made, as shown at *D*. These tubes may be firmly and tightly fitted by wrapping their ends with paper coated with glue before they are forced into their holes.

Get a small piece of the thinnest sheet rubber you can find, or a piece of thin linen paper, and, having rubbed glue on the board *A* around the shallow hole, stretch the thin rubber, or paper, over this hole and glue it there. Then rub glue on the block *B*, and place the shallow hole in this block directly over the shallow hole in *A*, and fasten *B* to *A* by wrapping twine around these blocks. Thus you will have made a little box divided into two compartments by a

partition of thin rubber Fasten the rod *A* to the side of a small board, so that it may stand upright

Attach a piece of large-sized rubber tube to the glass tube *E*, and into the other end of the tube

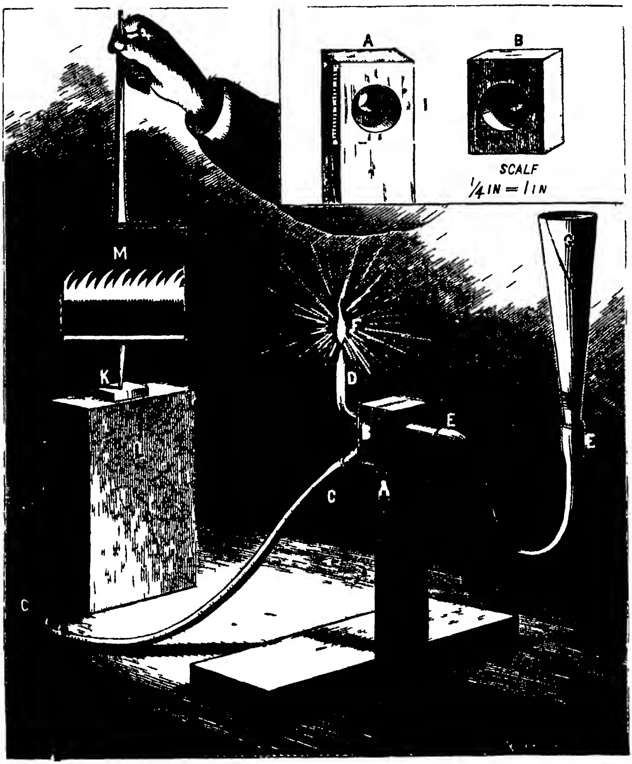


FIG 51.

stick a cone, made by rolling up a piece of cardboard so as to form a cone 8 inches long and with a mouth 2 inches (51 millimetres) in diameter.

Now get a piece of wood 1 foot long, 4 inches wide, and ¼ inch thick. Out of this cut the square, with the two rods projecting from it, as shown at *M*. The lower of these rods is short, the one above the square is long. Cut the end of the shorter rod to a blunt point, and with this point make a very shallow pit in the piece of flat wood *K* for the rod and square to twirl in. Glue the piece of wood *K* on the end of a brick, *L*. Get two pieces of thin silvered glass, each 4 inches square, and, placing one on each side of the square *M*, fasten them there by winding twine around the top and bottom borders of the mirrors.

EXPERIMENT 112.—Through a rubber tube lead gas to *C*. It will go into the left-hand partition of the box and will come out at *F*, where you will light it. Now place the mirror-rod in the shallow pit in *K*, and hold the mirror upright so that you may see the flame *F* reflected from its centre.

Hold the rod upright and twirl it slowly between the thumb and forefinger, which should point downward and not horizontally, as shown in the figure. The flame appears in the mirror drawn out into a band of light with a smooth top-border. While twirling the mirror put the cone to your mouth and sing into it. The sonorous vibrations enter the side *A* of the box, and, striking on the thin rubber, force this in and out. When it goes in, a puff of gas is driven out of the other partition, *B*, of the box, and the flame *F* jumps up. When the sheet of rubber vibrates outward, it sucks the gas into the box *B*, and the flame *F* jumps down. Therefore, on singing into the funnel, you will see in the mirror the smooth top-border of the luminous band broken up into little tongues or teeth of flame, each tooth standing for one vibration of the voice on the rubber partition.

Place a lamp-chimney around the flame, should the wind from the twirling mirror agitate it, and be careful not to have the flame too high.

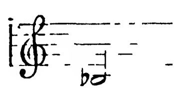
EXPERIMENT 113.—Another way of showing the vibrations of the flame is to burn the jet of gas at the end of a glass tube stuck into the end of a rubber tube attached to *F*. Now sling the tube round in a vertical circle, and you have an unbroken luminous ring; but as soon as you sing into the cone this ring breaks up into a circle of beads of light, or sometimes changes into a wreath of beautiful little luminous flowers, like forget-me-nots. To make this experiment, you will be obliged to have a tube with a larger opening than that at *F*.

This instrument will afford you many an hour of instruction and amusement. We have only space to show you a few experiments. Others will suggest themselves whenever you use it.

EXPERIMENT 114.—Sing into the funnel the sound of *oo* as in p*oo*l. After a few trials you will get a pure simple sound, and the flame will appear as in Fig. 52. Some voices get this figure more readily by singing E.

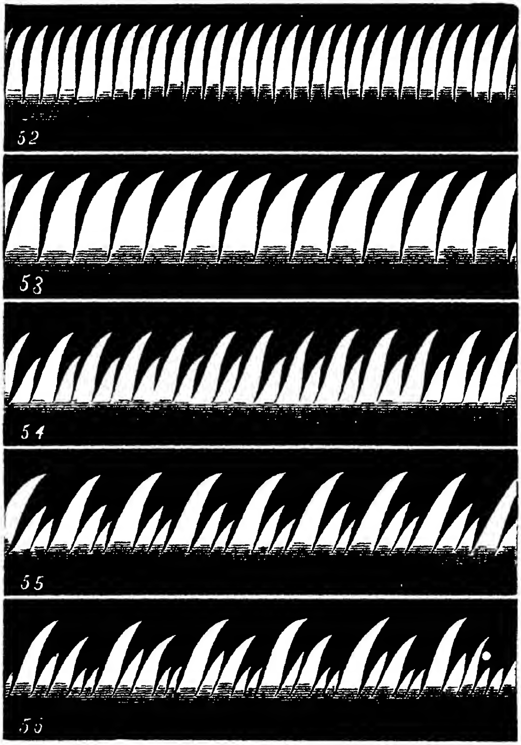
EXPERIMENT 115.—Twirling the mirror with the same velocity, gradually lower the pitch of the *oo* sound till your voice falls to its lower octave, when the flame will appear as in Fig. 53, with half the number of teeth in Fig 52, because the lower octave of a sound is given by half the number of vibrations.

EXPERIMENT 116.—Sing the vowel sound *o* on the



note and you will see Fig. 54 in the mirror. This evidently is not the figure that would have been made by a *simple* vibration. It shows that this *o* sound is compound, and formed of two simple sounds, one the octave of the other. The larger teeth are made by every alternate vibration of the higher simple sound acting with a vibration of the lower, and thus making

the flame jump higher by their combined action on the membrane



FIGS 52 53 54 55, 56

EXPERIMENT 117.—Fig 55 appears on the mirror when we sing the English vowel *a* on the note f.

EXPERIMENT 118.—Fig. 56 appears on the mirror when we sing the English vowel *a* on the note c.

Examine attentively Fig. 55. This shows that the English vowel *a* sung on f is made up of two combined simple vibrations. One of these alone would make the long tongues of flame, but with this simple vibration exists another of three times its frequency; that is, the vibration of greater frequency is the 3d harmonic of the slower. As the slower vibration, making the long tongues of flame, is f, the higher must be c″ of the second octave above f. Each third vibration of this higher harmonic coincides with each vibration of f; hence each third tongue of flame is higher than the others.

EXPERIMENT 119.—In like manner the student must analyze Fig. 56 into its simple sonorous elements. Then he should, with the vibrating flame, examine the peculiarities of the various voices of his friends, and make neat and accurate drawings of the flames corresponding to them, so that he may analyze them at his leisure.

EXPERIMENT 120.—Blow your toy trumpet into the paper cone gently, and then strongly, and observe that the sound given by the trumpet is a complex one. Try if you cannot get a flame somewhat like what the trumpet gives by singing *ah*, through your nose, into the cone.

The student will soon find that different persons, in singing the same note, as nearly alike as they can, will produce flames of very different forms. This is because the voices differ in the number and relative intensities of the simple sounds which form them.

Another cause of the different forms of flame obtained by different experimenters is due to the fact that they have used different lengths of tube leading from the cone to the membrane.

EXPERIMENT 121.—The fact can be readily shown by singing the same compound sound through different lengths of tube leading from the cone *G* to the membrane.

TERQUEM'S EXPERIMENT, IN WHICH KÖNIG'S FLAME IS USED INSTEAD OF THE EAR (AS IN EXPERIMENTS 68, 69, AND 70), AND THUS THE MOTIONS OF A VIBRATING DISK ARE MADE VISIBLE.

The method of analyzing the motions of a vibrating plate (as described in Experiments 68, 69, and 70), with the paper cone and tube applied to the ear, which has been used by us for a long time, has quite recently been adapted to M. König's flame by Professor Terquem, of Lille, who has thus made these motions visible to the student, and has given us a charming experiment.

EXPERIMENT 122.—If the rubber tube used in connection with the cone in Experiments 68, 69, and 70, is attached to the tube *E* of Fig. 51, instead of being placed in the ear, then Konig's flame will remain at rest when the cone is in position No. 1 of Experiment 68, or in position No. 3 of Experiment 70. In these positions of the cone you found that no sound was heard. But, when the mouth of the cone is placed in position No. 2 of Experiment 69, the flame becomes deeply serrated; and you found in Experiment 69 that in this position an intense sound was heard.

CHAPTER XVIII.

ON HOW WE SPEAK, AND ON THE TALKING MACHINES OF FABER AND EDISON.

HOW WE SPEAK.

THE little musical instrument with which we sing and speak is formed of two flexible membranes stretched side by side across a short tubular box placed on the top of the windpipe. This box is made of plates of cartilage, moveable on each other, and bound together with muscles and membranes.

The top of the windpipe is formed of a large ring of cartilage, called the *cricoid* (ring-shaped) cartilage. Jointed to this is a broad plate of gristle, called the *thyroid* (shield-shaped) cartilage. This cartilage is bent into the shape of a V. The legs of this V straddle over the cricoid and are jointed to its outer sides. The peak of the V stands up and points toward the front of your throat. You can feel it, as it is the "Adam's apple." On the back of the upper edge of the cricoid ring are jointed two small pointed cartilages, known as the *arytenoid* (funnel-shaped) cartilages. Stretching from these to the inner sides of the legs of the V of the thyroid are two membranes, one to each leg. These are the *vocal chords.*

When the point of the thyroid is not pulled down, these membranes are lax, and the breath from the windpipe passes freely between them and does not make them vibrate. (*See B* of Fig. 57.)

But when the peak of the thyroid is pulled down

by its muscles the vocal cords are stretched. At the same time the arytenoid cartilages move nearer each other, and the thin, sharply-cut edges of the vocal chords are brought parallel and quite close to each other, as is shown in *A* of Fig. 57. If the air is now forced through this narrow slit (called the *glottis*), the vocal chords vibrate just like the tongue in our toy trumpet, or like the reed in any reed-pipe. A puff of air passes between them; they separate; immediately afterward they come close together and the current of air is stopped. They again open, another puff goes into the cavity of the mouth, and then they

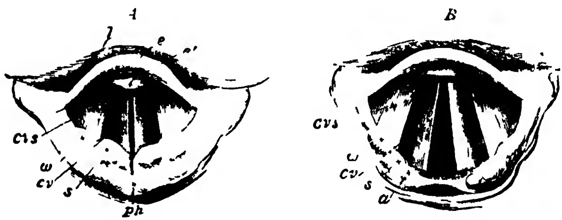


FIG. 57.

Figs. *A* and *B*.—Views of the human larynx from above, as actually seen by the aid of the instrument called the laryngoscope.

Fig. *A*.—In the condition when voice is being produced.

Fig. *B*.—At rest, when no voice is produced.

e. Epiglottis (foreshortened).

cv. The vocal cords.

cvs. The so called false vocal cords, folds of mucous membrane lying above the real vocal cords.

a. Elevation caused by the arytenoid cartilages.

s, *w*. Elevations caused by small cartilages connected with the arytenoids.

l. Root of the tongue.

close together again. Thus the glottis opens and closes with a frequency depending on the degree of stretch on the vocal chords.

Our experiments with Konig's flame have shown how composite are the sounds of the human voice. The quality of a voice depends on the number and relative intensities of the simple sounds which build it up.

SPEECH is voice modified and modulated by the movements of the parts of the cavity of the mouth, of the tongue and lips.

The oral cavity is made larger or smaller, longer or shorter, and thus, resounding to some lower or higher harmonic of the voice, makes the others feebly heard.

EXPERIMENT 123.—If you form your speaking organs to say *o*, and then take your vibrating A-fork and hold it before your lips, you will hear the cavity of the mouth resounding to this sound. On changing the vocal organs to say *e* the resonance ceases.

All the vowel sounds are formed by a steady voice modified by the resonance of the different sizes and shapes given to the oral cavity.

The consonants are made by obstructions placed at the beginning or end of the oral sounds, by the movements of the tongue and lips; but, as this is a book of experiments, I leave you to inform yourself by experiments as to these matters.

EXPERIMENTS IN WHICH A TOY TRUMPET TALKS AND A SPEAKING MACHINE IS MADE.

EXPERIMENT 124.—Sing *ah*, and while doing so quickly open and shut your lips twice. These two sudden obstructions to the sound have made you say *mama*. If you will observe attentively the motion of your mouth you will see that for the last syllable of mama you opened your mouth wider and kept it open longer than for the first syllable.

EXPERIMENT 125.—This is all we have to know to make our toy trumpet talk. You already have seen that its sounds, like those of the human voice, are made by puffs of air. These pass the reed every time it goes above or below the oblong hole in the plate in which it vibrates. Your experiments with Konig's flame have told you that the sounds of the

voice and trumpet are similar—that both are highly composite.

Let, then, the vibrating reed in the trumpet stand for your *vocal chords.* To get a resonant cavity like the *mouth,* make one between your two hands, as shown in *A* of Fig. 58. The funnel of the trumpet is placed inside this cavity, with the tube coming out in the crotch between the thumb and forefinger. The lips we will form of the fingers of one hand. By raising these together, more or less, from the other hand we can make a larger or smaller opening into the cavity between the palms of the hands, and thus get articulation.

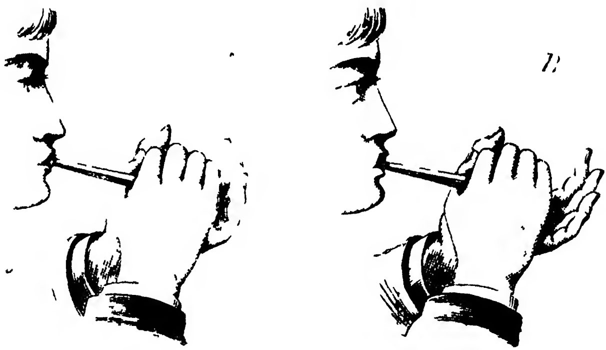


Fig. 58.

Now blow into the trumpet as though you were speaking *mama* into it, so that you may make it sound twice, each sound lasting just as long as the sounds in mă and mā. While making the first sound, raise the fingers as high as is shown in *A*; while making the second, raise them as high as is shown in *B*. The trumpet talks and says *mama* quite plainly.

EXPERIMENT 126.—Let us make a talking machine. Get an orange with a thick skin and cut it in halves.

With a sharp dinner-knife cut and scrape out its soft inside. You have thus made two hemispherical cups. Cut a small simicircle out of the edge of each cup. Place these over each other, and you have a hole for the tube of the trumpet to go out of the orange. Now sew the two cups together, except a length directly opposite the trumpet, for here are the *lips*. A peanut makes a good enough nose for a baby, and black beans make "perfectly lovely" eyes. Take the baby's cap and place it on the orange, and try if you can make it say

Fig. 59.

FABER'S TALKING MACHINE.

These simple experiments show the principles followed in the construction of the celebrated talking machine of Faber of Vienna. A vibrating ivory reed, of variable pitch, forms its vocal chords. There is an oral cavity whose size and shape can be rapidly changed by depressing the keys on a key-board.

Rubber tongue and lips make the consonants. A little windmill turning in its throat rolls the *r*, and a tube is attached to its nose when it speaks French. This is the anatomy of this really wonderful piece of mechanism.

EDISON'S TALKING PHONOGRAPH.

From the above description it is seen that Faber worked at the source of articulate sounds, and built up an artificial organ of speech, whose parts, as nearly as possible, perform the same functions as corresponding organs in our vocal apparatus. Faber attacked the problem on its physiological side. Quite differently

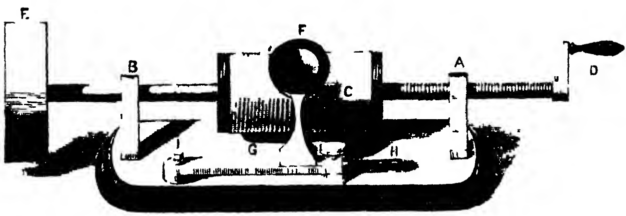


FIG. 60.

worked Mr. Edison. He attacked the problem, not at the source of origin of the vibrations which make articulate speech, but, considering the vibrations as already made, it matters not how, he makes these vibrations impress themselves on a sheet of metallic foil, and then reproduces from these impressions the sonorous vibrations which made them.

Faber solved the problem of making a machine speak by obtaining the mechanical *causes* of the vibrations making voice and speech; Edison solved it

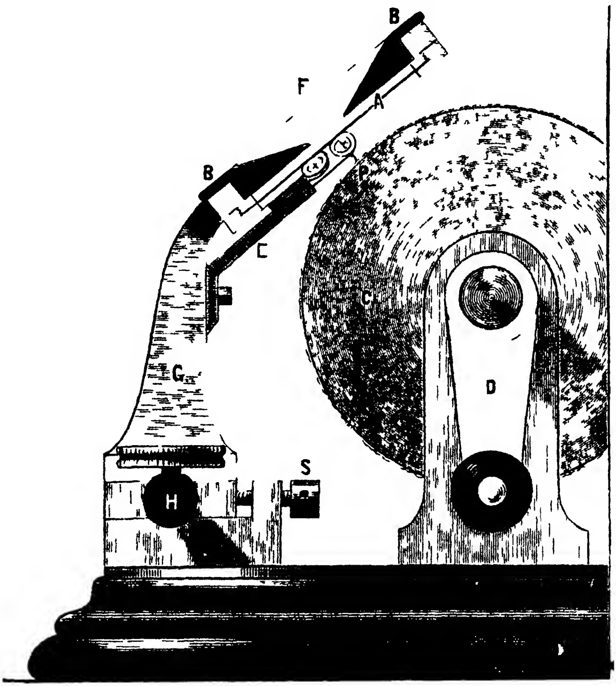
by obtaining the mechanical *effects* of these vibrations. Faber reproduced the movements of our vocal organs; Edison reproduced the motions which the drum-skin of the ear has when this organ is acted on by the vibrations *caused* by the movements of the vocal organs.

Figs. 60 and 61 will render intelligible the construction of Mr. Edison's machine. A cylinder, *F*, turns on an axle which passes through the two standards *A* and *B*. On one end of this axle is the crank *D*; on the other, the heavy fly-wheel *E*. The portion of this axle to the right of the cylinder has a screw-thread cut on it which, working in a nut in *A*, causes the cylinder to move laterally when the crank is turned. On the surface of the cylinder is scored the same thread as on its axle. At *A* (shown in $\frac{1}{2}$ scale in Fig. 61) is a plate of iron about $\frac{1}{100}$ inch thick. This plate can be moved toward and from the cylinder by pushing in or pulling out the lever *H G*, which turns in a horizontal plane round the pin *I*.

The under surface of this thin iron plate (*A*, Fig. 61) presses against short pieces of rubber tubing, *X* and *X*, which lie between the plate and a spring attached to *E*. The end of this spring carries a rounded steel point, *P*, which, when brought up to the cylinder by the motion of the handle *H*, enters slightly between the threads scored on the cylinder *C*. The distance of this point, *P*, from the cylinder is regulated by a set-screw, *S*, against which abuts the lever *H G*. Over the iron plate *A* is a disk of vulcanite, *B B*, with a hole in its centre. The under side of this disk nearly touches the plate *A*. Its upper surface is cut into a shallow, funnel-shaped cavity leading to the opening in its centre.

To work this machine we first neatly coat the cylinder with a sheet of foil; then we bring the point *P* to bear against this foil, so that, on turning the cylinder, it makes a depressed line or furrow where the foil covers the space between the threads

cut on the surface of the cylinder. The mouth is now placed close to the opening in the vulcanite disk *B B*, and *the metal plate is talked to*, while the cylinder is revolved with a uniform motion.



The thin iron plate *A* vibrates to the voice, and the point *P* indents the foil, impressing in it the varying numbers, amplitudes, and durations of these vibrations. If the vibrations given to the plate *A* are those of simple sounds, then they are of a uniform regular character, and the point *P* indents regular,

undulating depressions in the foil. If the vibrations are those causing complex and irregular sounds (like those of the voice in speaking), then similarly the depressions made in the foil are complex (like the curve of Fig. 49) and irregular. Thus the yielding and inelastic foil receives and *retains* the mechanical impressions of these vibrations with all of their minute and subtile characteristics.

Our experiment No. 121 has, however, taught us that the forms of these impressions will change with every change of distance of the place of origin of the compound sound from the vibrating plate *A*, even when at these various distances the compound sonorous vibrations fall on the plate with precisely the same intensity. Hence the futility of attempting to *read* sound-writings.

The permanent impressions of the vibrations of the voice are now made. It remains to show how the operation just described may be reversed, and we may thus *obtain from these impressions the aërial vibrations which made them.* Nothing is simpler. The plate *A*, with its point *P*, is moved away from the cylinder by pulling toward you the lever *H G*. Then the motion of the cylinder is reversed till you have brought opposite to the point *P* the beginning of the series of impressions which it has made on the foil. Now bring the point up to the cylinder; place against the vulcanite plate *B B* a large cone of paper or of tin to reenforce the sounds, and then steadily turn the crank *D*. The elevations and depressions which have been made by the point *P* now pass under this point, and in doing so they cause it and the thin iron plate to make over again the precise vibrations which animated them when they made these impressions under the action of the voice. The consequence of this is, that the iron plate gives out the vibrations which previously fell upon it, and *it talks back to you what you said to it.*

CHAPTER XIX.

ON HARMONY AND DISCORD. A SHORT EXPLANATION OF WHY SOME NOTES, WHEN SOUNDED TOGETHER, CAUSE AGREEABLE AND OTHERS DISAGREEABLE SENSATIONS.

IF, toward sunset, you walk on the shady side of a picket-fence, flashes of light will enter your eye every time you come to an opening between the pales. These flashes, coming slowly one after the other, cause a very disagreeable sensation in the eye. Similarly, if flashes or pulses of sound enter the ear, they cause a disagreeable sensation. Such pulses enter the ear when we listen to two sounding organ-pipes, two forks, or two wires on the sonometer which are slightly out of tune with each other. As you already know (*see* Experiment 71), these flashes or pulses of sound are called *beats.* You also know that the number of these beats made in a second is equal to the difference in the numbers of vibrations made in one second by the two sounding bodies Thus, if one sounding body makes 500 and the other 507 vibrations in a second, then 7 beats per second will be heard.

EXPERIMENT 127.—With your toy trumpet and the disk used in Rood's experiment in the reflection of sound, Fig. 42, you can make an excellent experiment, showing the effects of beats on your ear. Sound the trumpet, and gradually increase the velocity of the turning disk. At first the beats of sound so caused may be separately distinguished by

the ear, and, though not pleasant in their effect, yet they can be endured. As the frequency of the beats increases, the harshness of the sensation becomes greater and greater, until the effect on the ear becomes actually painful.

But, if the flashes of light or beats of sound succeed one another so rapidly that the sensation of one flash or beat remains till the next arrives, you will have continuous sensations that are not unpleasant. In other words, continuous sensations are pleasant, but discontinuous or broken sensations are disagreeable.

If two sonorous vibrations reach the ear together and make a disagreeable sensation, then we may be sure that the difference in the numbers of their vibrations gives a number of beats per second which do not follow one another with sufficient rapidity to blend into a smooth, unbroken sensation. In other words, these beats are so few in a second that the sensation of one disappears before the next arrives, and so *discord* is the sensation; but, if the frequency of the beats be sufficiently increased, the sensation of one remains till the next arrives, and the sensation is continuous, and we say that the two sounds are in *harmony*.

Therefore it at once appears that, if we only can find out the number of beats required in a second to blend sounds from different parts of the musical scale, we shall be able to state beforehand what notes when sounded together will make harmony and what notes will make discord.

By many experiments I have found the number of beats per second that two sounds must make to be in harmony. In the following table a few of the results of my experiments are given:

N	V	B	D
C	64	16	$\frac{1}{16}$ – ·0625 sec.
c	128	26	$\frac{1}{26}$ – ·0384 ,,
c′	256	47	$\frac{1}{47}$ – ·0212 ,,
g′	384	60	$\frac{1}{60}$ – ·0166 ,,
c″	512	78	$\frac{1}{78}$ – ·0128 ,,
e′	640	90	$\frac{1}{90}$ ·0111 ,,
g″	768	109	$\frac{1}{109}$ – ·0091 ,,
e‴	1024	135	$\frac{1}{135}$ – ·0074 ,,

Column N gives the names of the notes given by the vibrations per second in Column V. The c′ in this series is that used by physicists generally, and gives 256 vibrations In Column B is given the smallest number of beats per second which the corresponding sound must make with another in order that the two may be in harmony, or, as it is generally stated, may make with the other the *nearest consonant interval.* If 47 beats per second of c′, for example, blend, then the sensation of each of these beats remains on the ear $\frac{1}{47}$ of a second. In Column D are given these durations in fractions of a second. As these fractions are the lengths of time that the sensation of sound lingers in the ear after the vibrations of the air near the drum-skin of the ear have ceased, they are very properly called *the durations of the residual sonorous sensations*

You observe in the table that this duration becomes shorter as the pitch of the sound rises Thus, while the residual sensation of C is $\frac{1}{16}$ of a second, that of c‴ is only $\frac{1}{135}$.

Let us use the knowledge thus acquired by making it aid us in a few calculations and experiments. The table shows that if c′ is sounded with a note which makes with it 47 beats in a second, then these beats will fuse into one smooth, continuous sensation, and the notes must be in harmony. What is this note?

It is found in this manner: c′ is made by 256 vibrations per second, and the note which will make just 47 beats with it in a second must make 256 + 47 or 303 vibrations in a second. This number of vibrations makes a sound a little lower in pitch than ♭e′. This is the minor third of c′.

EXPERIMENT 128.—Now let one sing c′ while another sings ♭e′, and you will find that these sounds form an interval which is just within the range of harmony.

EXPERIMENT 129—Sing c′ and e′, then c′ and g′, and you will have yet more pleasant and smooth sensations.

EXPERIMENT 130.—But if one sings c′ while another sings d′ you have decided discord, an unpleasant rasping sensation in the ears. The reason of this is at once apparent: c′ makes 256 while d′ makes 288 vibrations in a second, and 288 less 256 gives 32 as the number of beats made in a second; but the table shows that 47 are needed in a second so that they may follow each other quick enough to blend.

Making similar calculations throughout five octaves, we have found the nearest consonant intervals for the c of each octave from C to c^{IV}. These are here given. It will be observed that this interval contracts as we ascend the musical scale—a fact which has been well established.*

*The nearest	consonant	interval of	C	is its	major third.
,,	,,	,,	c	,,	minor third.
,,	,,	,,	c′	,,	minor third, less ¼ semitone.
,,	,,	,,	c″	,,	minor third, less ½ semitone.
,,	,,	,,	c‴	,,	second.
,,	,,	,,	c^{IV}	,,	second, less ½ semitone.

Our experiments in sound have led us into music. We find that fundamental facts and laws of harmony may be explained by physiological laws—by rules according to which our sensations act. Music is the

sequence and concourse of sounds made in obedience to these laws. The explanation of many of these may be beyond our power; for the connection existing between æsthetic and moral feelings and sensations which cause them remains behind a veil. But it may be imagined that distant ages may bring forth man so highly organized that he may find his pleasure and pastime in

> "Untwisting all the chains that tie
> The hidden soul of harmony."

THE END.

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